THE WORK OF HERTZ AND HIS SUCCESSORS.

BEING A DESCRIPTION OF THE METHOD OF

SIGNALLING ACROSS SPACE WITHOUT WIRES BY ELECTRIC WAVES.

PROF. OLIVER LODGE, F.R.S.

SECOND EDITION.

LONDON:
"THE ELECTRICIAN" PRINTING AND PUBLISHING COMPANY, LIMITED,
SALISBURY COURT, FLEET STREET.

Yours truly
H. Hertz

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o/p

Works by Dr. O. J. LODGE.

Lightning Conductors and Lightning Guards.
Pioneers of Science.
Modern Views of Electricity.
Elementary Mechanics.
Protection of Buildings from Lightning.
Secondary Batteries and the Electrical Storage of Energy.

7.

THE WORK OF HERTZ

AND

SOME OF HIS SUCCESSORS.

Introductory.

THE untimely end of a young and brilliant career cannot fail to strike a note of sadness and awaken a chord of sympathy in the hearts of his friends and fellow-workers. Of men thus cut down in the early prime of their powers there will occur to us here the names of Fresnel, of Carnot, of Clifford, and now of Hertz. His was a strenuous and favoured youth; he was surrounded from his birth with all the influences that go to make an accomplished man of science—accomplished both on the experimental and on the mathematical side. The front rank of scientific workers is weaker by his death, which occurred on January 1, 1894, the thirty-seventh year of his life. Yet did he not go till he had effected an achievement which will hand his name down to posterity as the founder of an epoch in experimental physics.

In mathematical and speculative physics others had sown the seed. It was sown by Faraday, it was sown by Thomson and by Stokes, by Weber also doubtless, and by Helmholtz; but in this particular department it was sowed by none more fruitfully and plentifully than by Clerk Maxwell. Of the seed thus sown Hertz reaped the fruits. Through his experimental discovery, Germany awoke to the truth of Clerk Maxwell's theory of light, of light and electricity combined, and the able army of workers in that country (not forgetting some in Switzerland, France, and Ireland) have done most of the gleaning after Hertz.

This is the work of Hertz which is best known, the work which brought him immediate fame. It is not always that public notice is so well justified. The popular instinct is generous and trustful, and it is apt to be misled. The scientific eminence accorded to a few energetic persons by popular estimate is more or less amusing to those working on the same lines. In the case of Hertz no such mistake has been made. His name is not over well-known, and his work is immensely greater in every way than that of several who have made more noise.

His best known discovery is by no means his only one. I have here a list of eighteen Papers contributed to German periodicals by him, in addition to the Papers incorporated in his now well-known book on electric waves. I would like to suggest that it would be an act of tribute, useful to students in this country, if the Physical Society of London saw their way to translate and publish a collection of, at any rate, some of these Papers :—

1878-79. *Wied. Ann.*, 1880, vol. 10, p. 414. Experiments to establish an Upper Limit for the Kinetic Energy of Electric Flow.

1880. Inaugural Dissertation (Doctor Thesis) on Induction in Rotating Spheres.

1881. Vol. 13, *Wied. Ann.*, p. 266. On the Distribution of Electricity on the Surface of Moving Conductors.

1881. Crelle, vol. 92, p. 156. On the Contact of Solid Elastic Bodies.

1881. Vol. 14, *Wied. Ann.*, p. 581. Upper Limits for the Kinetic Energy of Moving Electricity.

1882. *Verhandlungen des Vereins des Gewerbfleisses* (Sonderabdruck). On the Contact of Solid Elastic Bodies and on Hardness.

1882. *Wied. Ann.*, vol. 17, p. 177. On the Evaporation of Liquids, especially of Quicksilver, in Air-Free Space, and on the Pressure of Mercury Vapour.

1882. *Verhandln. d. phys. Gesellschaft in Berlin*, p. 18. On a New Hygrometer.

1883. March. *Schlömilch Zeitschrift*, p. 125. On the Distribution of Pressures in an Elastic Circular Cylinder.

1883. *Wied. Ann.*, vol. 19, p. 78. On an appearance accompanying Electric Discharge.

1883. *Ib.*, vol. 19, p. 782. Experiments on Glow Discharge.

1883. *Wied. Ann.*, vol. 20, p. 279. On the Property of Benzine as an Insulator and as showing Elastic Reaction (Rückstandsbildner).

1883. *Zeitschrift für Instrumentenkunde*. Dynamometric Contrivance of Small Resistance and Infinitesimal Self-Induction.

1884. *Met. Zeitschrift*, November-December. Graphic Methods for the Determination of the Adiabatic Changes of Condition of Moist Air.

1884. *Wied. Ann.*, vol. 22, p. 449. On the Equilibrium of Floating Elastic Plates.

1884. *Ib.*, vol. 23. On the Connection between Maxwell's Electrodynamic Fundamental Equations and those of Opposition Electrodynamics.

1885. *Ib.*, vol. 24, p. 114. On the Dimension of a Magnetic Pole in different Systems of Units.

1887-1889. Papers incorporated in his book, "Ausbreitung der Elektrischen Kraft," translated under the title of "Electric Waves."

1892. *Wied. Ann.*, vol. 45, p. 28. On the Passage of Cathode Rays through Thin Metal Sheets.

Portrait Slide.

The portrait exhibited at the lecture, though excellent as a photograph, failed to represent Hertz at his best ; perhaps because it was not taken till after the pharyngeal trouble had set in which ultimately carried him off. The frontispiece to this pamphlet, a steel-plate contributed by the Proprietors of *The Electrician*, is here used to replace it, with advantage.

In closing these introductory and personal remarks, I should like to say that the enthusiastic admiration for Hertz's spirit and character, felt and expressed by students and works who came into contact with him, is not easily to be exaggerated. Never was a man more painfully anxious to avoid wounding the susceptibilities of others ; and he was accustomed to deprecate the prominence given to him by speakers and writers in this country, lest it might seem to exhalt him unduly above other and older workers among his own sensitive countrymen.

Speaking of the other great workers in physics in Germany, it is not out of place to record the sorrow with which we have heard of the recent death of Dr. August Kundt, Professor in the University of Berlin, successor to Von Helmholtz in that capacity.

When I consented to discourse on the work of Hertz, my intention was to repeat some of his actual experiments, and especially to demonstrate his less-known discoveries and observations. But the fascination exerted upon me by electric oscillation experiments, when I, too, was independently working at them in the spring of

1888,* resumed its hold, and my lecture will accordingly consist of experimental demonstrations of the outcome of Hertz's work rather than any precise repetition of portions of that work itself.

In case a minority of my audience are in the predicament of not knowing anything about the subject, a five minutes' explanatory prelude may be permitted, though time at present is very far from being "infinitely long."

The simplest way will be for me hastily to summarise our knowledge of the subject before the era of Hertz.

Just as a pebble thrown into a pond excites surface ripples, which can heave up and down floating straws under which they pass, so a struck bell or tuning-fork emits energy into the air in the form of what are called sound waves, and this radiant energy is able to set up vibrations in other suitable elastic bodies.

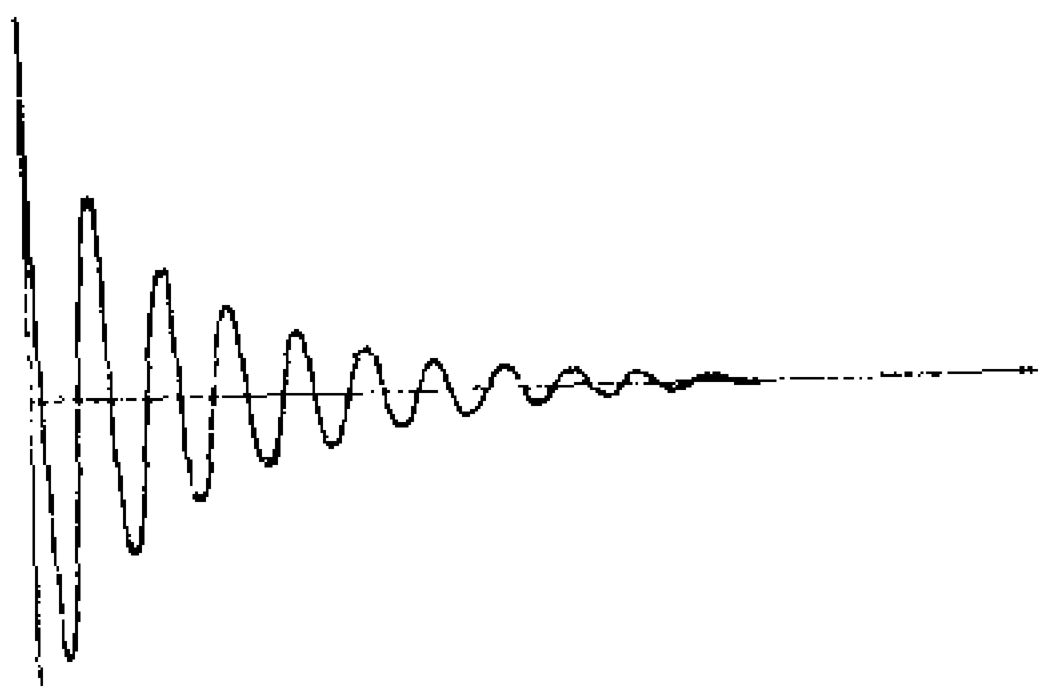

FIG. 1.—Oscillations of Dumb-bell Hertz Vibrator (after Bjerknes).

If the body receiving them has its natural or free vibrations violently damped, so that when left to itself it speedily returns to rest (Fig. 1), then it can respond fully to notes of almost any pitch. This is the case with your ears and the tones of my voice. Tones must be exceedingly shrill before they cease to excite the ear at all.

If, on the other hand, the receiving body has a persistent period of vibration, continuing in motion long after it is left to itself (Fig. 2) like another tuning-fork or bell, for instance, then far more facility of response exists, but great accuracy of tuning is

* *Phil. Mag.*, XXVI. pp. 229, 230 August, 1888 ; or "Lightning Conductors and Lightning Guards" (Whittaker), pp. 104, 105 ; also *Proc. Roy. Soc.*, Vol. 50, p. 27.

necessary if it is to be fully called out; for if the receiver is not thus accurately syntonised with the source, it fails more or less completely to resound.

Conversely, if the *source* is a persistent vibrator, correct tuning is essential, or it will destroy at one moment (Fig. 3) motion which it originated the previous moment. Whereas, if it is a dead-beat or

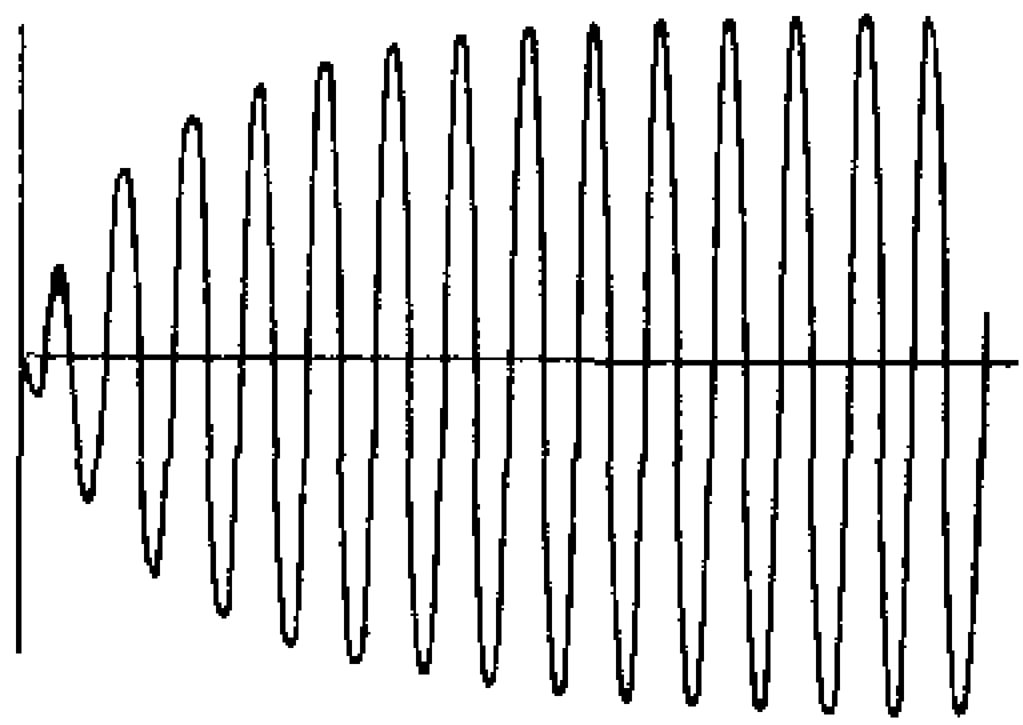

FIG. 2.—Oscillation of Ring-shaped Hertz Resonator excited by syntonic Vibrator (after Bjerknes).

strongly-damped exciter, almost anything will respond equally well or equally ill to it.

What I have said of sounding bodies is true of all vibrators in a medium competent to transmit waves. Now a sending telephone or a microphone, when spoken to, emits waves into the ether, and

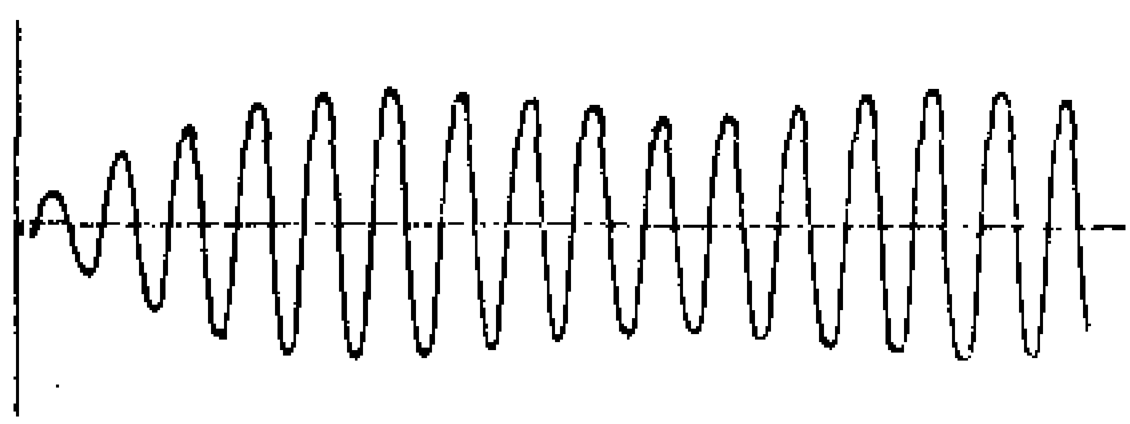

FIG. 3.—Oscillation of Ring Resonator not quite syntonic with Radiator. (For method of obtaining these curves see Fig. 14.)

this radiant energy is likewise able to set up vibration in suitable bodies. But we have no delicate means of directly detecting these electrical or etherial waves; and if they are to produce a perceptible effect at a distance, they must be confined, as by a speaking-tube, prevented from spreading, and concentrated on the distant receiver.

This is the function of the telegraph wire; it is to the ether what a speaking-tube is to air. A metal wire in air (*in function*, not in details of analogy) is like a long hollow cavity surrounded by nearly rigid but slightly elastic walls.

Sphere charged from Electrophorus.

Furthermore, any conductor electrically charged or discharged with sufficient suddenness must emit electrical waves into the ether, because the charge given to it will not settle down instantly, but will surge to and fro several times first; and these surgings or electric oscillations must, according to Maxwell, start waves in the ether, because at the end of each half-swing they cause electrostatic, and at the middle of each half swing they cause electromagnetic effects, and the rapid alternation from one of these modes of energy to the other constitutes etherial waves.* If a wire is handy they will run along it, and may be felt a long way off. If no wire exists they will spread out like sound from a bell, or light from a spark, and their intensity will decrease according to the inverse square of the distance.

Maxwell and his followers well knew that there would be such waves; they knew the rate at which they would go, they knew that they would go slower in glass and water than in air, they knew that they would curl round sharp edges, that they would be partly absorbed but mainly reflected by conductors, that if turned back upon themselves they would produce the phenomena of stationary waves, or interference, or nodes and loops; it was known how to calculate the length of such waves, and even how to produce them of any required or predetermined wave-length from 1,000 miles to a foot. Other things were known about them which would take too long to enumerate; any homogeneous insulator would transmit them, would refract or concentrate them if it were of suitable shape, would reflect none of a particular mode of vibration at a certain angle, and so on, and so on.

* Strictly speaking, in the waves themselves there is no lag or difference of phase between the electric and the magnetic vibrations; the difference exists in emitter or absorber, but not in the transmitting medium. True radiation of energy does not begin till about a quarter wave-length from the source, and within that distance the initial quarter period difference of phase is obliterated.

All this was *known*, I say, known with varying degrees of confidence; but by some known with as great confidence as, perhaps even more confidence than, is legitimate before the actuality of experimental verification.

Hertz supplied the verification. He inserted suitable conductors in the path of such waves, conductors adapted for the occurrence in them of induced electric oscillations, and to the surprise of everyone, himself doubtless included, he found that the secondary electric surgings thus excited were strong enough to display themselves by minute electric sparks.

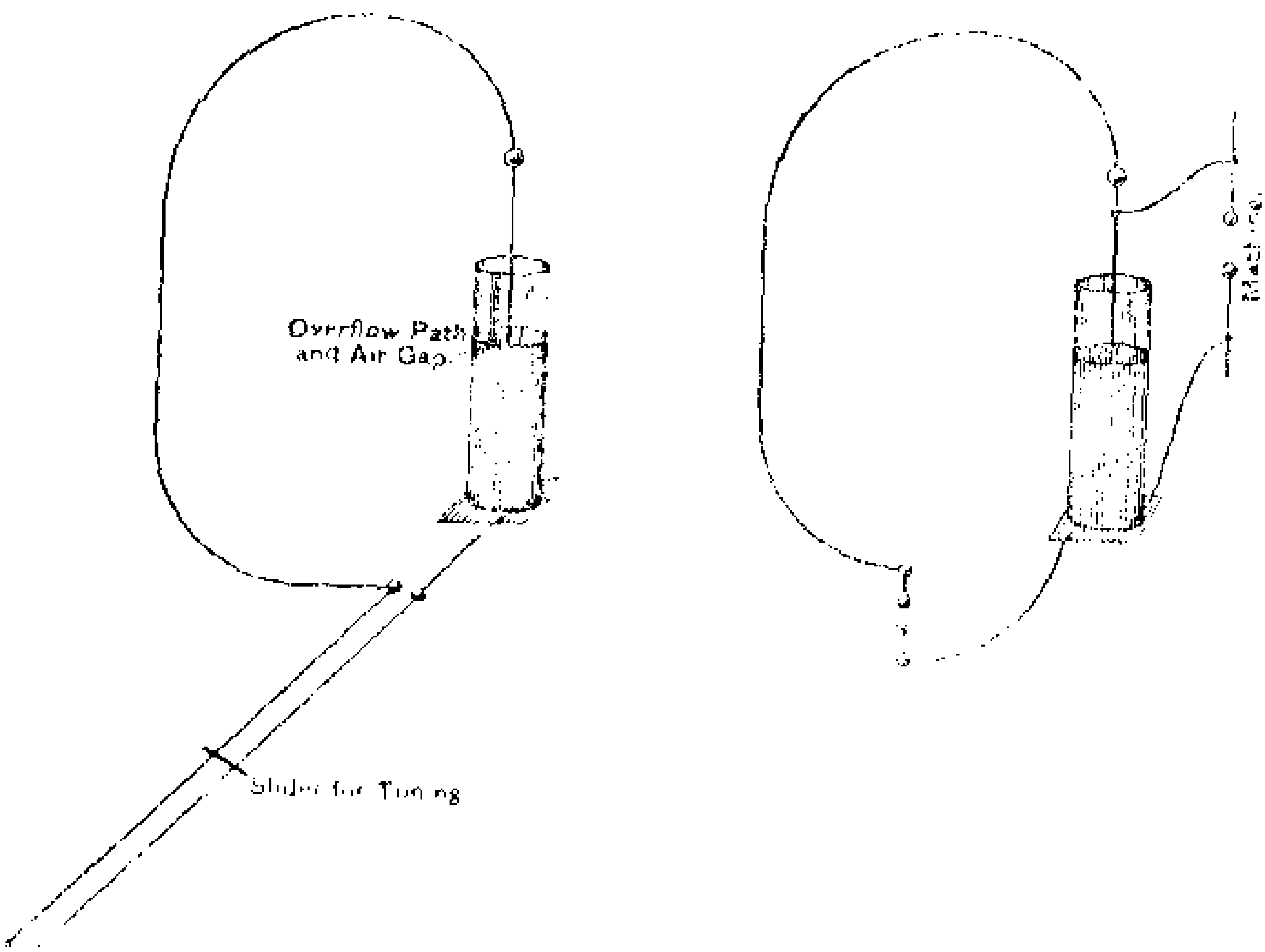

FIG. 4.—Experiment with Syntonic Leyden Jars.

Syntonic Leyden Jars.

I shall show this in a form which requires great precision of tuning or syntony, both emitter and receiver being persistently vibrating things giving some 30 or 40 swings before damping has a serious effect. I take two Leyden jars with circuits about a yard in diameter, and situated about two yards apart (Fig. 4). I charge and discharge one jar, and observe that the surgings set up in the other can cause it to overflow if it is syntonised with the first.*

* See *Nature*, Vol. XLI., p. 368; or J. J. Thomson, "Recent Researches," p. 395.

A closed circuit such as this is a feeble radiator and a feeble absorber, so it is not adapted for action at a distance. In fact, I doubt whether it will visibly act at a range beyond the $\frac{1}{4}\lambda$ at which true radiation of broken-off energy occurs. If the coatings of the jar are separated to a greater distance, so that the dielectric is more exposed, it radiates better; because in true radiation the electrostatic and the magnetic energies are equal, whereas in a ring circuit the magnetic energy greatly predominates. By separating the coats of the jar as far as possible we get a typical Hertz vibrator (Fig. 5), whose dielectric extends out into the room, and this radiates very powerfully.

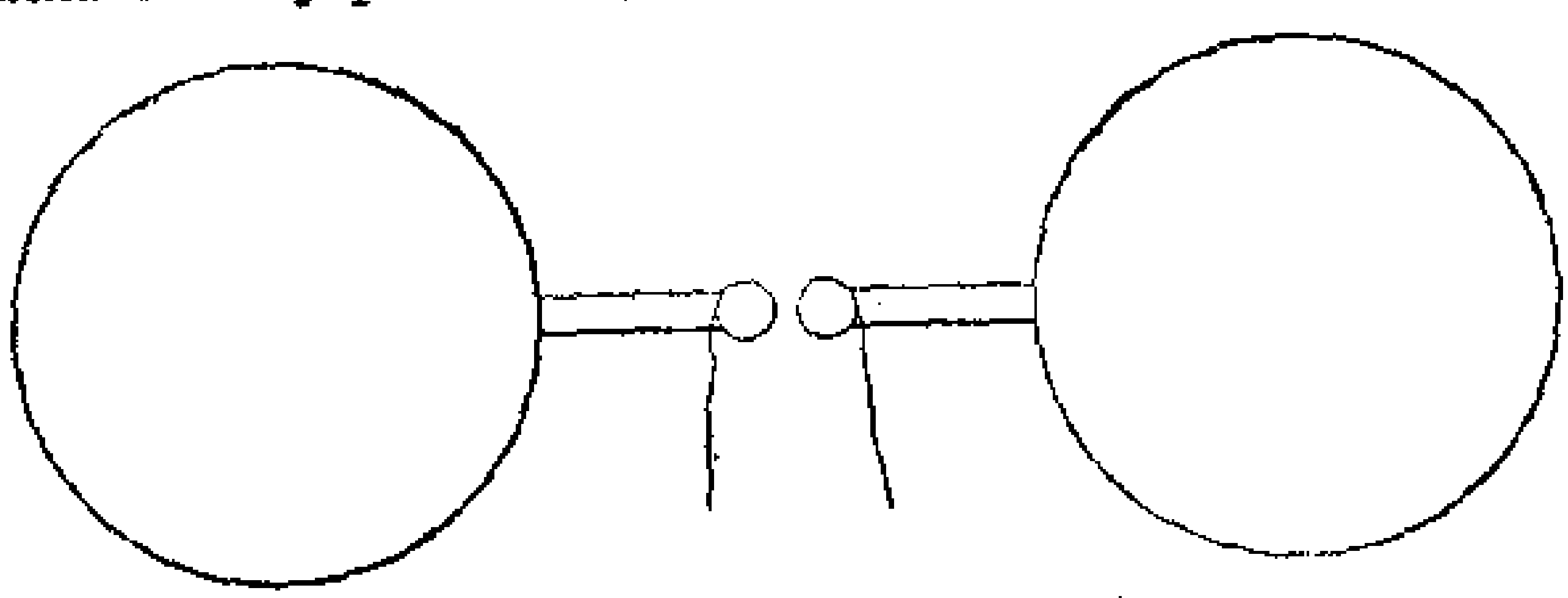

FIG. 5.—Standard Hertz Radiator.

Ordinary Size Hertz Vibrator.

In consequence of its radiation of energy, its vibrations are rapidly damped, and it only gives some three or four good strong swings (Fig. 1). Hence it follows that it has a wide range of excitation; *i.e.*, it can excite sparks in conductors barely at all in tune with it.

The two conditions, conspicuous energy of radiation and persistent vibration electrically produced, are at present incompatible. Whenever these two conditions coexist, considerable power or activity will, of course, be necessary in the source of energy. At present they only coexist in the sun and other stars, in the electric arc, and in furnaces.

Two Circular Vibrators sparking in sympathy.

The receiver Hertz used was chiefly a circular resonator (Fig. 6), not a good absorber but a persistent vibrator, well adapted for picking up disturbances of precise and measurable wave-length. Its mode of vibration when excited by emitter in tune with it is

depicted in Fig. 2. I find that the circular resonators can act as senders too ; here is one exciting quite long sparks in a second one.

Electric Syntony: that was his discovery, but he *did not* stop there. He at once proceeded to apply his discovery to the verification of what had already been predicted about the waves, and by laborious and difficult interference experiments he ascertained that

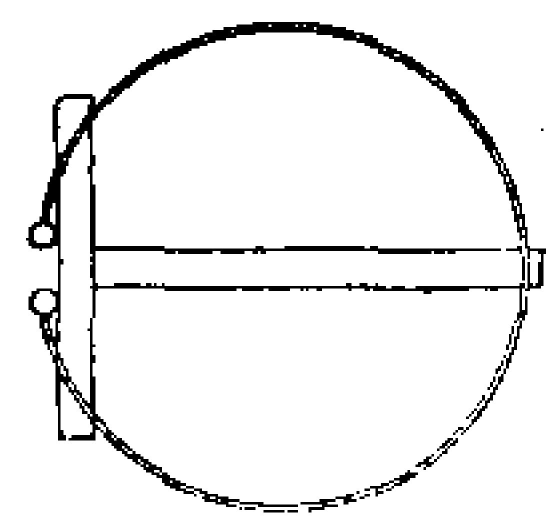

FIG. 6.—Circular Resonator. (The knobs ought to nearly touch each other.)

the previously calculated length of the waves was thoroughly borne out by fact. These interference experiments in free space are his greatest achievement.

He worked out every detail of the theory splendidly, separately analysing the electric and the magnetic oscillation, using language

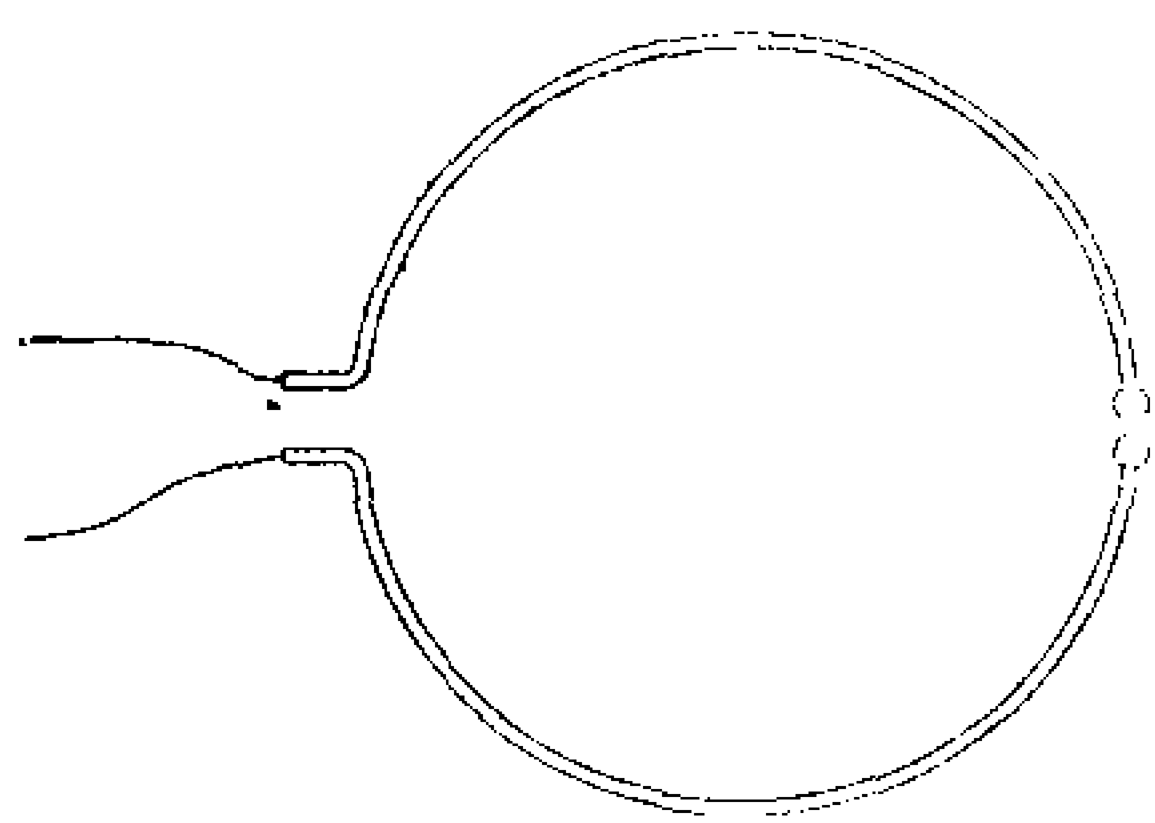

FIG. 6A.—Any circular resonator can be used as a sender by bringing its knobs near the sparking knobs of a coil ; but a simple arrangement is to take two semi-circles, as in above figure, and make them the coil terminals. The capacity of the cut ends can be varied, and the period thereby lengthened, by expanding them into plates.

not always such as we should use now, but himself growing in theoretic insight through the medium of what would have been to most physicists a confusing maze of troublesome facts, and disentangling all their main relations most harmoniously.

Holtz Machine, A and B Sparks; Glass and Quartz Panes in Screen.

While Hertz was observing sparks such as these, the primary or exciting spark and the secondary or excited one, he observed as a bye issue that the secondary spark occurred more easily if the light from the primary fell upon its knobs. He examined this new influence of light in many ways, and showed that although spark light and electric brush light were peculiarly effective, any source of light that gave very ultra-violet rays produced the same result.

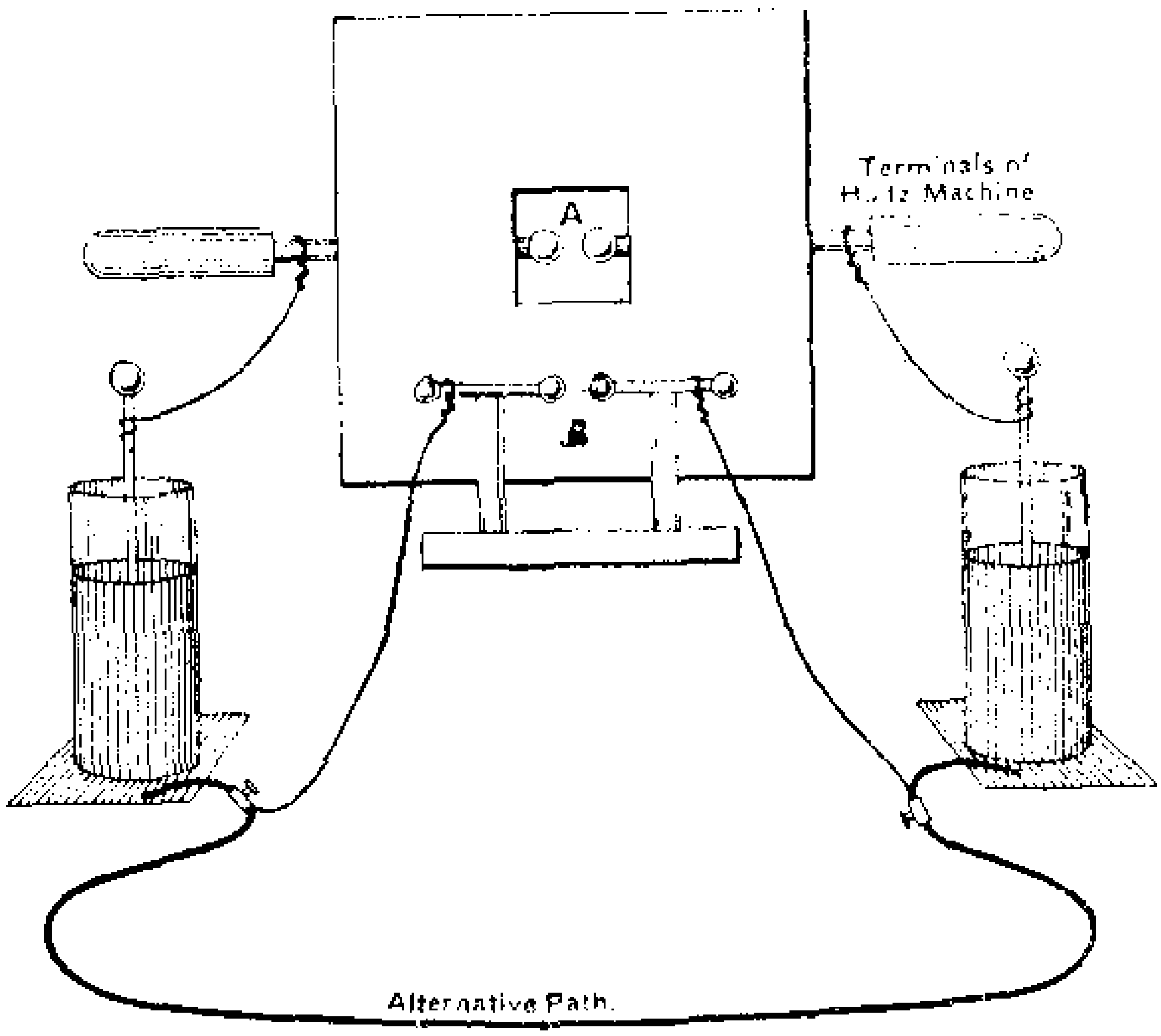

FIG. 7.—Experiment arranged to show effect on one spark of light from another. The **B** spark occurs more easily when it can see the **A** spark through the window, unless the window is glazed with glass. A quartz pane transmits the effect.

The above figure represents my way of showing the experiment. It will be observed that with this arrangement the **B** knobs are at the same potential up to the instant of the flash, and at the same potential up to the instant of the flash, and in that case the ultra-violet portion of the light of the **A** spark assists the occurrence of the **B** spark. But it is interesting to note what Elster and Geitel have found (*see* Appendix I., Fig. A), that if the **B** knobs were subjected to steady strain instead of to impulsive rush—*e.g.*, if

they were connected to the inner coats of the jars instead of the outer coatings—that then the effect of ultra-violet light on either spark-gap would exert a deterrent influence, so that the spark would probably occur at the other, or non-illuminated, gap. With the altered connections it is, of course, not feasible to illuminate *one spark by the light of the other; the sparks are then alternative, not successive.*

Wiedemann and Ebert, and a number of experimenters, have repeated and extended this discovery, *proving that it is the cathode* knob on which illumination takes effect; and Hallwachs and Righi made the important observation, which Elster and Geitel, Stoletow,

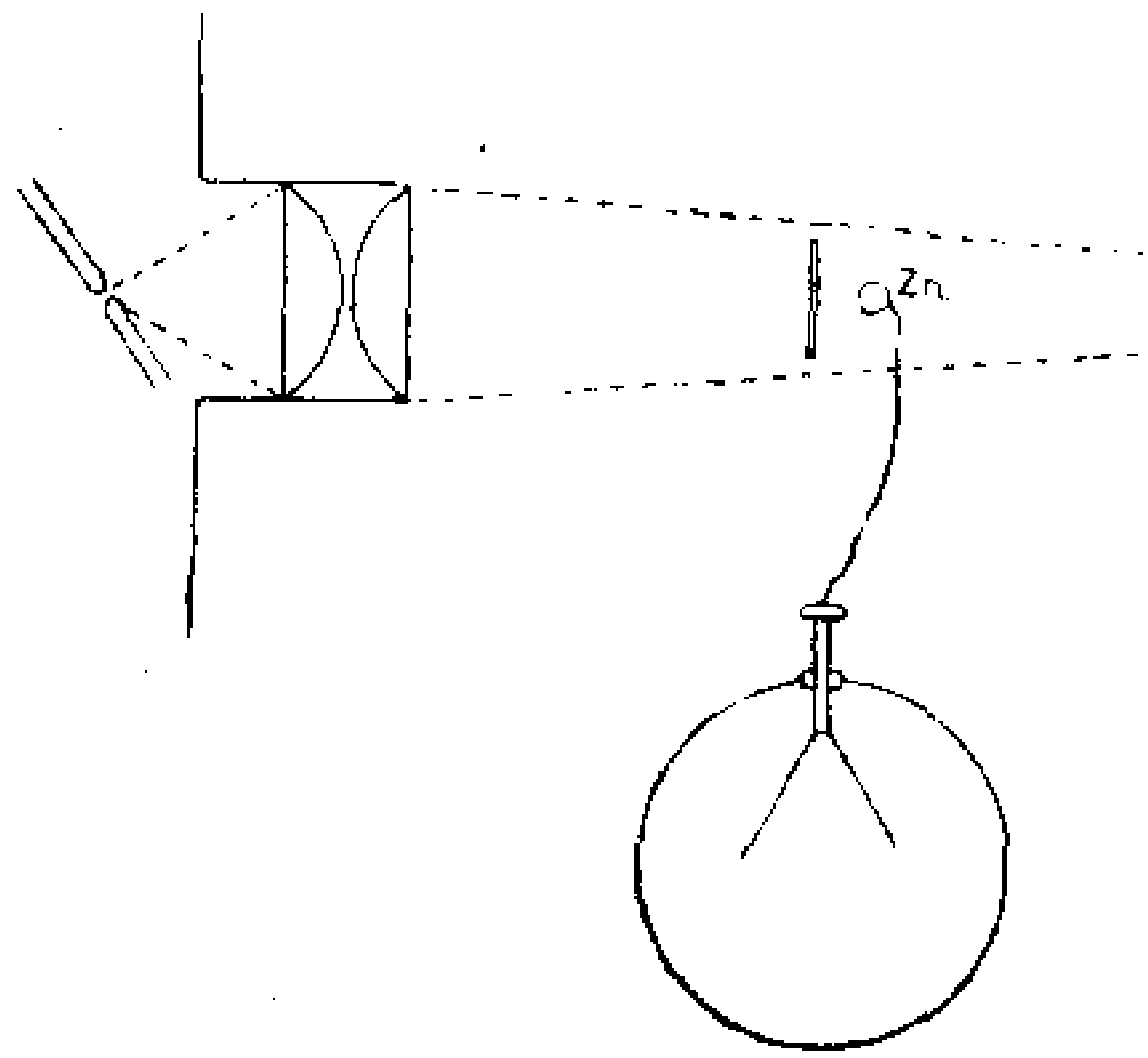

FIG. 8.—Zinc Rod in Arc Light, protected by Glass Screen. The lenses are of quartz, but there is no need for any lenses in this experiment; leakage begins directly the glass plate is withdrawn.

Branly, and others have extended, that a freshly-polished zinc or other oxidisable surface, if charged negatively, is gradually discharged by ultra-violet light.

It is easy to fail in reproducing this experimental result if the right conditions are not satisfied; but if they are it is absurdly easy, and the thing might have been observed nearly a century ago.

Zinc discharging Negative Electricity in Light; Gold Leaf Electroscope; Glass and Quartz Panes; Quartz Prism.

Take a piece of zinc, clean it with emery paper, connect it to a gold leaf electroscope, and expose it to an arc lamp. (Fig. 8). If

charged positively nothing appears to happen, the action is very slow; but a negative charge leaks away in a few seconds if the light is bright. Any source of light rich in ultra-violet rays will do; the light from a spark is perhaps most powerful of all. A pane of glass cuts off all the action; so does atmospheric air in sufficient thickness (at any rate, town air), hence sunlight is not powerful. A pane of quartz transmits the action almost undiminished, but fluor-spar may be more transparent still. Condensing the arc rays with a quartz lens and analysing them with a quartz prism or reflection grating, we find that the most effective part of the light is high up in the ultra-violet, surprisingly far beyond the limits of the visible spectrum* (Fig. 9).

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* While preparing for the lecture it occurred to me to try, if possible during the lecture itself, some new experiments on the effect of light on negatively charged bits of rock and ice, because if the effect is *not limited* to metals it must be important in connection with atmospheric electricity. When Mr. Branly *coated an aluminium plate with an insulating* varnish, he found that its charge was able to soak in and out of the varnish during *illumination* (*Comptes Rendus*, Vol. CX., p. 898, 1890). Now, the mountain tops of a negatively charged earth are exposed to very ultra-violet rays, and the air is a dielectric in which quiet up-carrying and sudden downpour of electricity could go on in a manner not very unlike the well-known behaviour of water vapour; and this perhaps may be the reason, or one of the reasons, why it is not unusual to experience a thunderstorm after a few fine days. I have now tried these experiments on such geological fragments as were handy, and find that *many of them discharge negative* electricity under the action of a naked arc, especially from the side of the *specimens which was somewhat dusty, but that* when wet they discharge much less rapidly, and when positively charged hardly at all. Ice and garden soil discharge negative electrification, too, under ultra-violet illumination, but not so quickly as limestone, mica schist, ferruginous quartz, clay, and some other specimens. Granite barely acts; it seems to insulate too well. The ice and soil were tried in their usual moist condition, but, when thoroughly dry, soil discharges quite rapidly. No rock tested was found to discharge as quickly as does a *surface of perfectly bright* metal, such as iron, but many discharged much more quickly than ordinary dull iron, and *rather more quickly than when the* bright iron surface was thinly oiled or wetted with water. To-day (June 5) I find that the leaves of Geranium discharge positive electrification five times as quickly as negative, under the action of an arc-light, and that glass cuts the effect off while quartz transmits it. [For Elster and Geitel's experiments, and those of Righi, *see* Appendix].

This is rather a digression, but I have taken some pains to show it properly because of the interest betrayed by Lord Kelvin on this matter, and the caution which he felt about accepting the results of the Continental experimenters too hastily.

It is probably a chemical phenomenon, and I am disposed to express it as a modification of the Volta contact effect* with illumination.

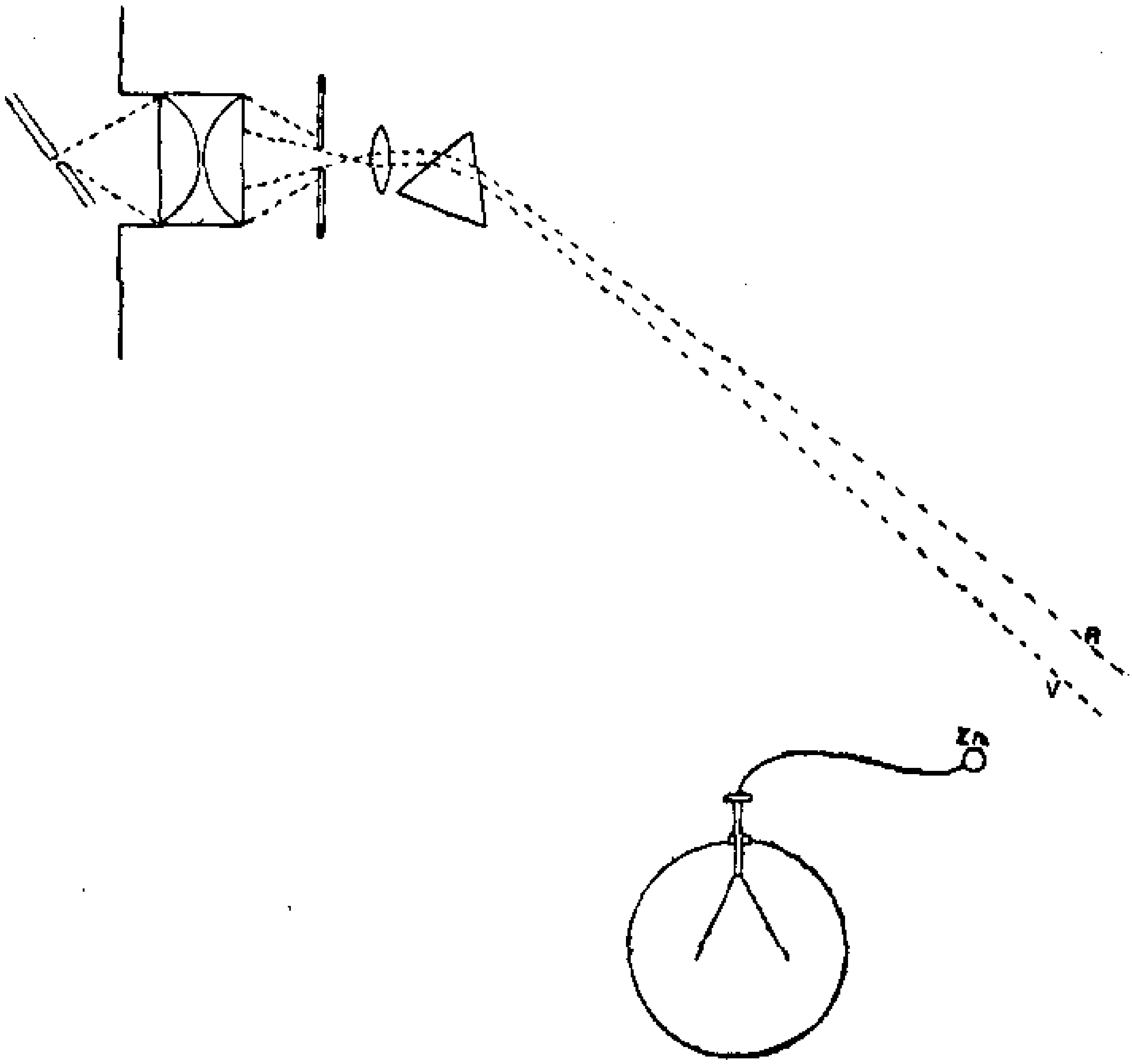

FIG. 9.—Zinc Rod discharging Negative Electricity in the very Ultra-violet Light of a Spectrum formed by a Quartz Train.

Return now to the Hertz vibrator, or Leyden jar with its coatings well separated, so that we can get into its electric as well as its magnetic field. Here is a great one giving waves 30 metres long, radiating while it lasts with an activity of 100 H.P., and making ten million complete electric vibrations per second.

* See Brit. Assoc. Report, 1884, pp. 502-519, or *Phil. Mag.*, Vol. XIX., pp. 267-352.

Large Hertz Vibrator in Action; Abel's Fuse; Vacuum Tube Striking of an Arc.

Its great radiating power damps it down very rapidly, so that it does not make above two or three swings; but nevertheless, each time it is excited, sparks can be drawn from most of the reasonably elongated conductors in this theatre.

A suitably situated gas-leak can be ignited by these induced sparks. An Abel's fuse connecting the water pipes with the gas pipes will blow off; vacuum tubes connected to nothing will glow (this fact has been familiar to all who have worked with Hertz waves since 1889), electric leads, if anywhere near each other, as they are in some incandescent lamp holders, may spark across to each other, thus striking an arc and blowing their fuses. This blowing of fuses by electric radiation frequently happened at Liverpool till the suspensions of the theatre lamps were altered.

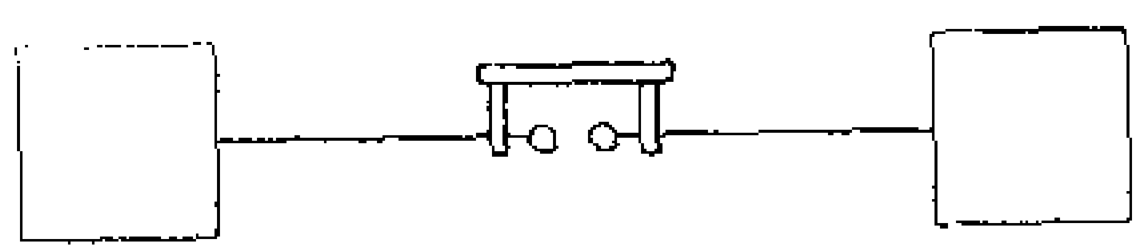

FIG. 10.—Hertz Oscillator on reduced scale, $\frac{1}{16}$th inch to a foot.

The striking of an arc by the little reverberating sparks between two lamp-carbons connected with the 100-volt mains I incidentally now demonstrate. An arc is started directly the large Hertz vibrator is excited at a distance.

There are some who think that lightning flashes can do none of these secondary things. They are mistaken.

Specimens of Emitters and Receivers.

On the table are specimens of various emitters and receivers such as have been used by different people; the orthodox Hertz radiator of dumb-bell type (Fig. 5), and the orthodox Hertz receivers:—a circular ring (Fig. 6) for interference experiments, because it is but little damped, and a straight wire for receiving at a distance, because it is a much better absorber. Beside these are the spheres and ellipsoids (or elliptical plates), which I have mainly used (Fig. 19) because they are powerful radiators and absorbers, and because their theory has been worked out by Horace Lamb and J. J. Thomson. Also dumb-bells (Fig. 11) without

air-gap, and many other shapes, the most recent of mine being the inside of a hollow cylinder with sparks at ends of a diameter (Fig. 12); this being a feeble radiator, but a very persistent vibrator,* and, therefore, well adapted for interference and diffraction experiments. But, indeed, spheres can be made to vibrate longer than

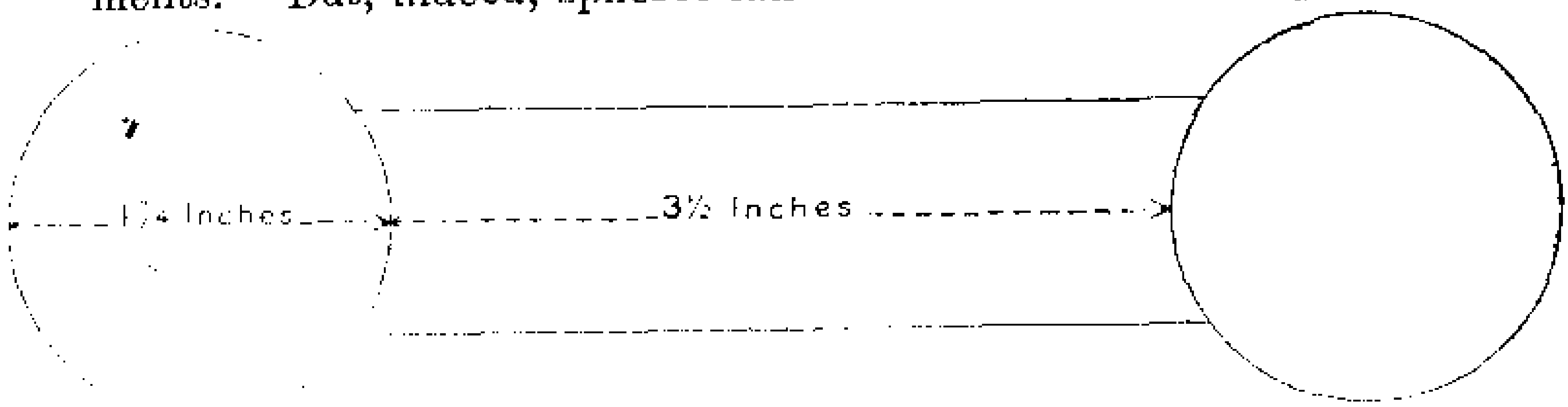

FIG. 11.—A Dumb-bell Form of Radiator.

usual by putting them into copper hats or enclosures, in which an aperture of varying size can be made to let the waves out (Figs. 20 and 21).

Many of these senders will do for receivers too, giving off sparks to other insulated bodies or to earth ; but, besides the Hertz type

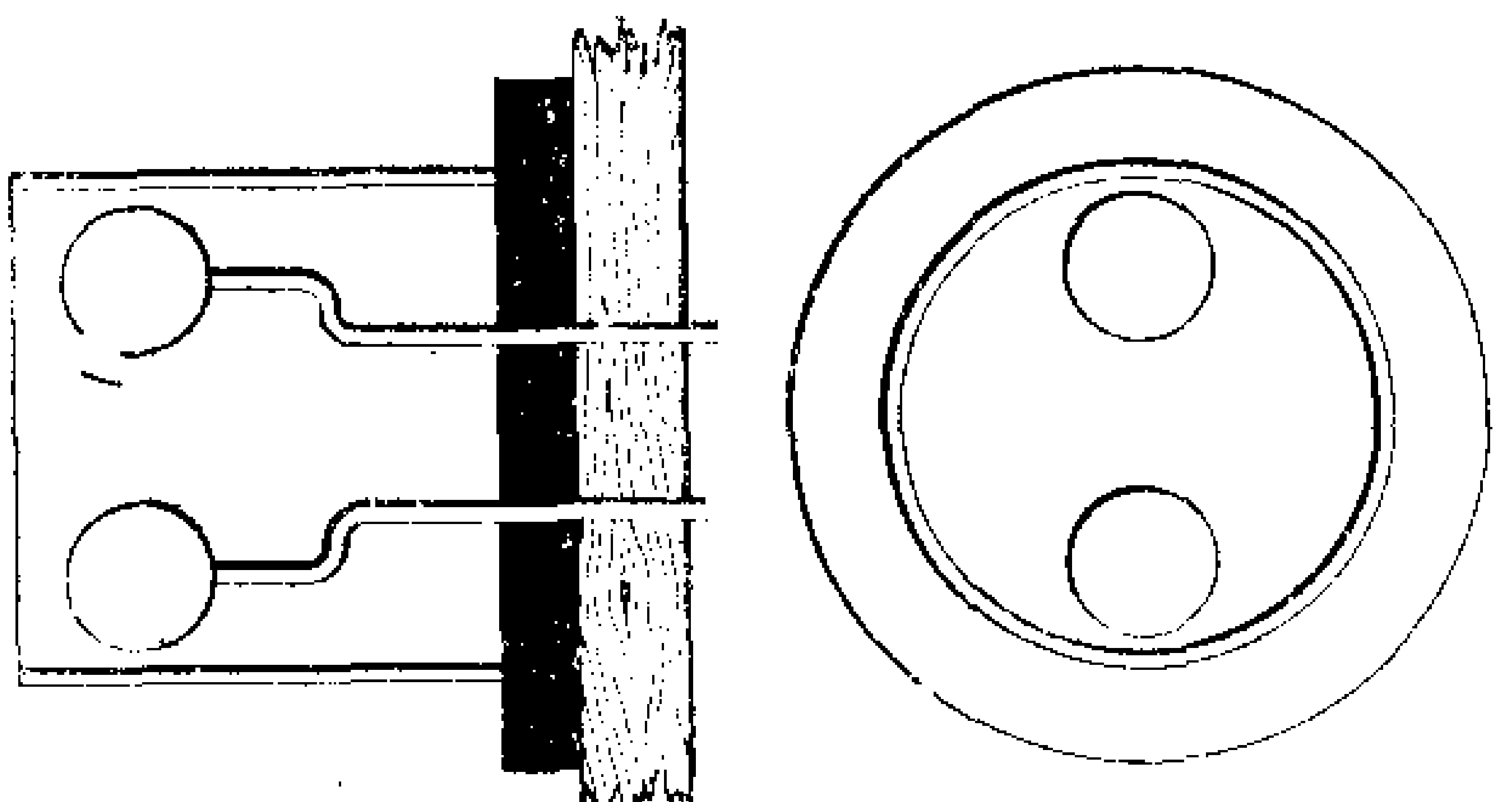

FIG. 12.—Dr. Lodge's Hollow Cylindrical Radiator, arranged horizontally against the Outside of a Metal-lined Box. Half natural size. Emitting 3in. waves.

of receiver, many other detectors of radiation have been employed. Vacuum tubes can be used, either directly or on the trigger principle, as by Zehnder (Fig. 13),† the resonator spark precipitating a discharge from some auxiliary battery or source of energy, and so making a feeble disturbance very visible. Explosives may be used

* J. J. Thomson, "Recent Researches," 344.

† *Wied. Ann.*, XLVII., p. 77.

for the same purpose, either in the form of mixed water-gases or in the form of an Abel's fuse. Fitzgerald found that a tremendously sensitive galvanometer could indicate that a feeble spark had passed, by reason of the consequent disturbance of electrical equilibrium which settled down again through the galvanometer.* This was the method he used in this theatre four years ago. Blyth used a one-sided electrometer, and V. Bjerknes has greatly developed this method (Fig. 14), abolishing the need for a spark, and making the electrometer metrical, integrating, and satisfactory.† With this detector many measurements have been made at Bonn by Bjerknes, Yule, Barton, and others on waves concentrated and kept from space dissipation by guiding wires.

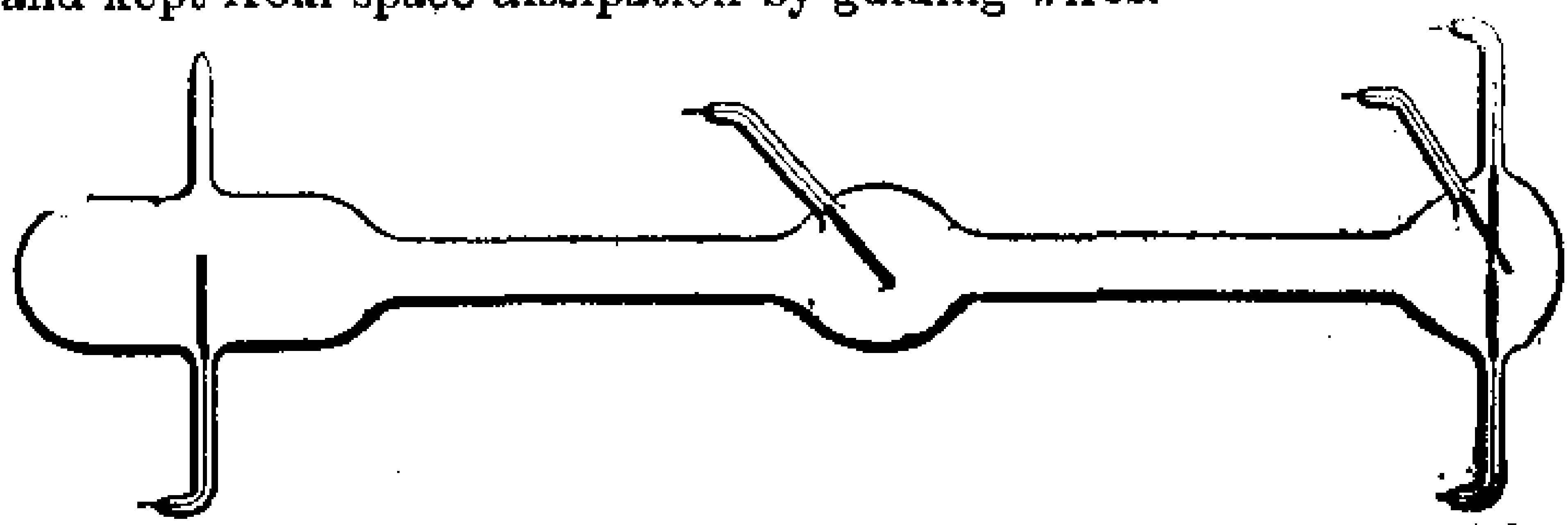

FIG. 13.—Zehnder's Trigger Tube. Half Natural Size. The two right-hand terminals, close together, are attached to the Hertz receiver; another pair of terminals are connected to some source just not able to make the tube glow until the scintilla occurs and makes the gas more conducting—as observed by Schuster and others.

Mr. Boys has experimented on the mechanical force exerted by electrical surgings, and Hertz also made observations of the same kind.

Various Detectors.

Going back to older methods of detecting electrical radiation, we have, most important of all, a discovery made long before man existed, by a creature that developed a sensitive cavity on its skin; a creature which never so much as had a name to be remembered by (though perhaps we now call it trilobite). Then, in recent times we recall the photographic plate and the thermopile, with its modification, the radiomicrometer; also the so-called bolometer, or otherwise-known Siemens' pyrometer, applied to astronomy by

* Fitzgerald, *Nature*, Vol. XLI., p. 295, and Vol. XLII., p. 172.

† *Wied. Ann.*, 44, p. 74.

Langley, and applied to the detection of electric waves in wires by Rubens and Ritter and Paalzow and Arons. The thermal junction was applied to the same purpose by Kolacek, D. E. Jones, and others.

And, before all these, the late Mr. Gregory, of Cooper's Hill, made his singularly sensitive expansion meter, whereby waves in free space could be detected by the minute rise of temperature they caused in a platinum wire, a kind of early and sensitive form of Cardew voltmeter.

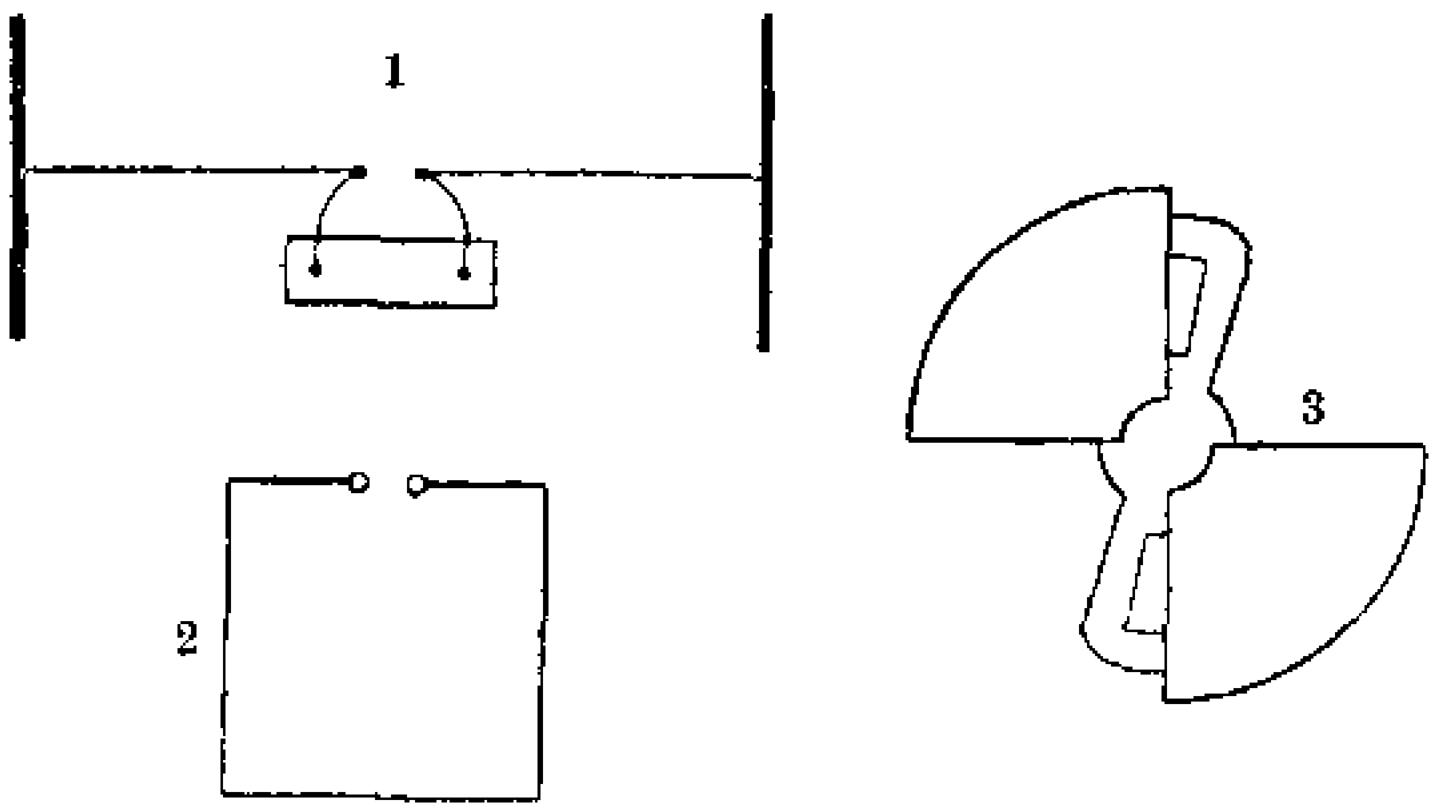

FIG. 14.—Bjerknes' Apparatus, showing (1) a Hertz vibrator connected to an induction coil; (2) a nearly-closed-circuit receiver properly tuned with the vibrator; and (3) a one-sided electrometer for inserting in the air-gap of 2. The receiver is not provided with knobs, as shown, but its open circuit is terminated by the quadrants of the electrometer, which is shown on an enlarged scale alongside. The needle is at zero potential and is attracted by both quadrants. By calculation from the indications of this electrometer Bjerknes plotted the curves 1, 2, and 3 on pages 4 and 5. Fig. 1 represents the oscillations of the primary vibrator, rapidly damped by radiation of energy. Fig. 2 represents the vibrations thereby set up in the resonating circuit when the two are accurately in tune; and which persist for many swings. Fig. 3 shows the vibrations excited in the same circuit when slightly out of tune with the exciter. A receiver of this kind makes many swings before it is seriously damped.

Going back to the physiological method of detecting surgings, Hertz tried the frog's-leg nerve and muscle preparation, which to the steadier types of electrical stimulus is so surpassingly sensitive, and to which we owe the discovery of current electricity. But he failed to get any result. Ritter has succeeded; but, in my experience, failure is the normal and proper result. Working with my colleague, Prof. Gotch, at Liverpool, I too have tried the nerve and

muscle preparation of the frog (Fig. 15), and we find that an excessively violent stimulus of a rapidly alternating character, if pure and unaccompanied by secondary actions, produces no effect—no stimulating effect, that is, even though the voltage is so high that sparks are ready to jump between the needles in direct contact with the nerve.

All that such oscillations do, if continued, is to produce a temporary paralysis or fatigue of the nerve, so that it is unable to transmit the nerve impulses evoked by other stimuli, from which paralysis it recovers readily enough in course of time.

This has been expected from experiments on human beings, such experiments as Tesla's and those of d'Arsonval. But an entire animal is not at all a satisfactory instrument wherewith to attack the question ; its nerves are so embedded in conducting tissues that it may easily be doubted whether the alternating type of

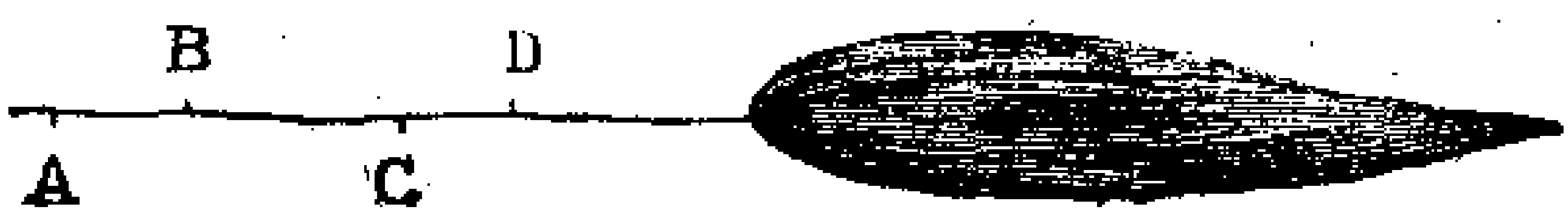

Fig. 15.—Experiment of Gotch and Lodge on the physiological effect of rapid pure electric alternations. Nerve-muscle preparation, with four needles, or else non-polarisable electrodes applied to the nerve. C and D are the terminals of a rapidly alternating electric current from a conductor at zero potential, while A and B are the terminals of an ordinary very weak galvanic or induction coil stimulus only just sufficient to make the muscle twitch.

stimulus ever reaches them at all. By dissecting out a nerve and muscle from a deceased frog after the historic manner of physiologists, and applying the stimulus direct to the nerve, at the same time as some other well known $\frac{1}{100}$th of a volt stimulus is applied to another part of the same nerve further from the muscle, it can be shown that rapid electric alternations, if entirely unaccompanied by static charge or by resultant algebraic electric transmission, evoke no excitatory response until they are so violent as to give rise to secondary effects such as heat or mechanical shock. Yet, notwithstanding this inaction, they gradually and slowly exert a paralysing or obstructive action on the portion of the nerve to which they are applied, so that the nerve impulse excited by the feeble just perceptible $\frac{1}{100}$th-volt stimulus above is gradually throttled

on its way down to the muscle, and remains so throttled for a time varying from a few minutes to an hour after the cessation of the violence.

I did not show this experiment at the lecture, but we hope to show it to the Physiological Section at Oxford.

Air Gap and Electroscope charged by Glass Rod and discharged by moderately distant Sphere excited by Coil.

Among trigger methods of detecting electric radiation, I have spoken of the Zehnder vacuum tubes; another method is one used by Boltzmann.* A pile of several hundred volts is on the verge

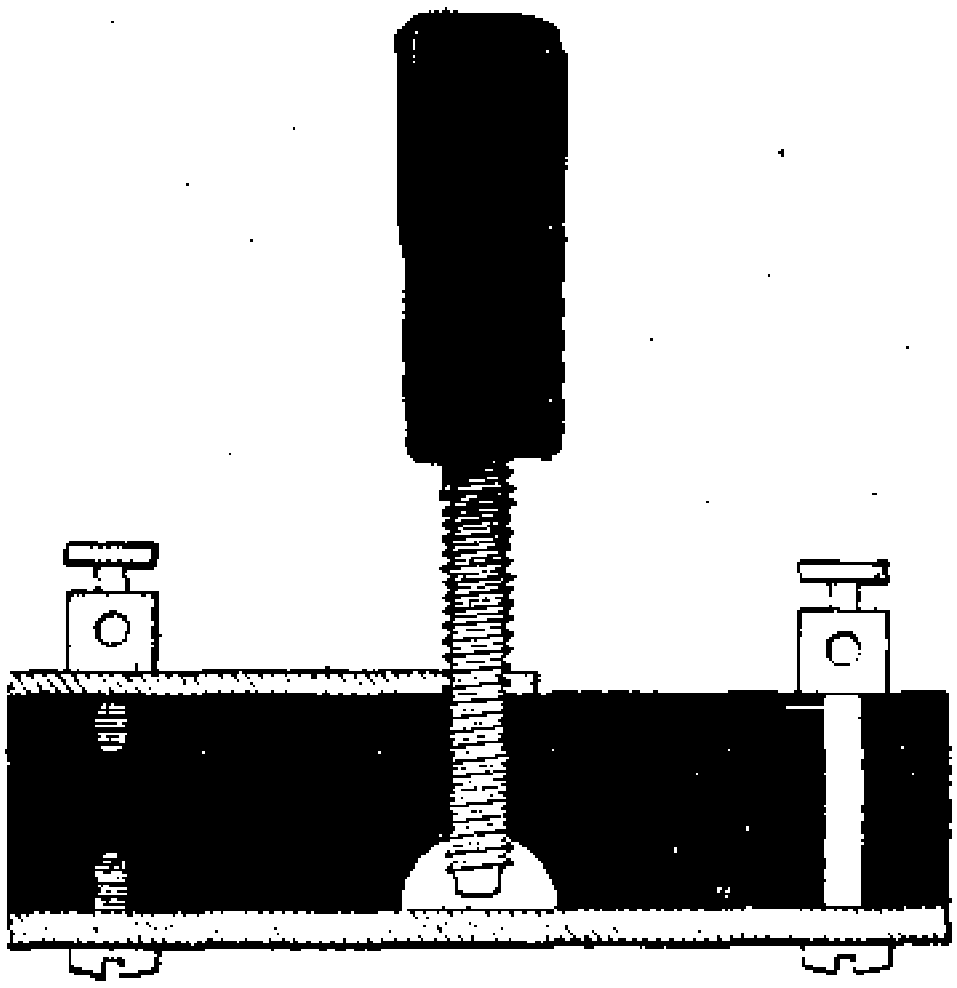

FIG. 16.—Air-gap for Electroscope. Natural Size. The bottom plate is connected to, and represents, the cap of an electroscope; the "knob" above it, mentioned in text, is the polished end of the screw, whose terminal is connected with the case of the instrument or "earth."

of charging an electroscope through an air gap just too wide to break down. Very slight electric surgings precipitate the discharge across the gap, and the leaves diverge. I show this in a modified and simple form. On the cap of an electroscope is placed a highly-polished knob or rounded end connected to the sole, and just not touching the cap, or rather just not touching a plate connected with the cap (Fig. 16), the distance between knob and plate being almost infinitesimal, such a distance as is appreciated in spherometry. Such an electroscope overflows suddenly and completely with any gentle rise of potential. Bring excited

* *Wied. Ann.*, 40, p. 399.

glass near it, the leaves diverge gradually and then suddenly collapse, because the air space snaps; remove the glass, and they rediverge with negative electricity; the knob above the cap being then charged positively, and to the verge of sparking. In this condition any electrical waves, collected if weak by a foot or so of wire projecting from the cap, will discharge the electroscope by exciting surgings in the wire, and so breaking down the air-gap. The chief interest about this experiment seems to me the extremely definite dielectric strength of so infinitesimal an air space. Moreover, it is a detector for Hertz waves that might have been used last century; it might have been used by Benjamin Franklin.

For to excite them no coil or anything complicated is necessary; it is sufficient to flick a metal sphere or cylinder with a silk handkerchief and then discharge it with a well-polished knob. If it is not well polished the discharge is comparatively gradual, and the vibrations are weak; the more polished are the sides of an air-gap, the more sudden is the collapse and the more vigorous the consequent radiation, especially the radiation of high frequency, the higher harmonics of the disturbance.

For delicate experiments it is sometimes well to repolish the knobs every hour or so. For metrical experiments it is often better to let the knobs get into a less efficient but more permanent state. This is true of all senders or radiators. For the generation of the, so to speak, "infra-red" Hertz waves any knobs will do, but to generate the "ultra-violet" high polish is essential.

Microphonic Detectors.

Receivers or detectors which for the present I temporarily call microphonic are liable to respond best to the more rapid vibrations. Their sensitiveness is to me surprising, though of course it does not approach the sensitiveness of the eye; at the same time, I am by no means sure that the eye differs from them in kind. It is these detectors that I wish specially to bring to your notice.

Prof. Minchin, whose long and patient work in connection with photo-electricity is now becoming known, and who has devised an instrument more sensitive to radiation than even Boys' radiomicrometer, in that it responds to the radiation of a star while the radiomicrometer does not, found some years ago that some of his

light-excitable cells lost their sensitiveness capriciously on tapping, and later he found that they frequently regained it again while Mr. Gregory's Hertz-wave experiments were going on in the same room.

These "impulsion-cells," as he terms them, are troublesome things for ordinary persons to make and work with—at least I have never presumed to try—but in Mr. Minchin's hands they are surprisingly sensitive to electric waves.*

The sensitiveness of selenium to light is known to everyone, and Mr. Shelford Bidwell has made experiments on the variations of conductivity exhibited by a mixture of sulphur and carbon.

Nearly four years ago M. Edouard Branly found that a burnished coat of porphyrised copper spread on glass diminished its resistance enormously, from some millions to some hundreds of ohms when it was exposed to the neighbourhood, even the distant neighbourhood, of Leyden jar or coil sparks. He likewise found that a tube of metallic filings behaved similarly, but that this recovered its original resistance on shaking.† Mr. Croft exhibited this fact recently at the Physical Society. M. Branly also made pastes and solid rods of filings, in Canada balsam and in sulphur, and found them likewise sensitive.‡

With me the matter arose somewhat differently, as an outcome of the air-gap detector employed with an electroscope by Boltzmann. For I had observed in 1889 that two knobs sufficiently close together, far too close to stand any voltage such as an electroscope can show, could, when a spark passed between them, actually cohere; conducting an ordinary bell-ringing current if a single voltaic cell was in circuit; and, if there were no such cell, exhibiting an electromotive force of their own sufficient to disturb a low resistance galvanometer vigorously, and sometimes requiring a faintly perceptible amount of force to detach them. The experiment was described to the Institution of Electrical Engineers,§ and Prof. Hughes said he had observed the same thing.

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* *Phil. Mag.*, Vol. XXXI., p. 223.

† Dr. Dawson Turner exhibited the experiment at the Edinburgh meeting of the British Association in 1892.

‡ E. Branly, *Comptes Rendus*, Vol. CXI., p. 785; and Vol. CXII., p. 90.

§ *Journal* Institution of Electrical Engineers, 1890, Vol. XIX., pp. 352-4; or "Lightning Conductors and Lightning Guards" (Whittaker), pp. 382-4.

Coherer in open, responding to Feeble Stimuli :—Small Sphere, Gas-lighter, Distant Sphere, Electrophorus.

Well, this arrangement, which I call a coherer, is the most astonishingly sensitive detector of Hertz waves. It differs from an actual air-gap in that the insulating film is not really insulating ; the film breaks down not only much more easily, but also in a less discontinuous and more permanent manner, than an air-gap. A tube of filings, being a series of bad contacts, clearly works on the same plan ; and though a tube of filings is by no means so sensitive, yet it is in many respects easier to work with, and, except for very

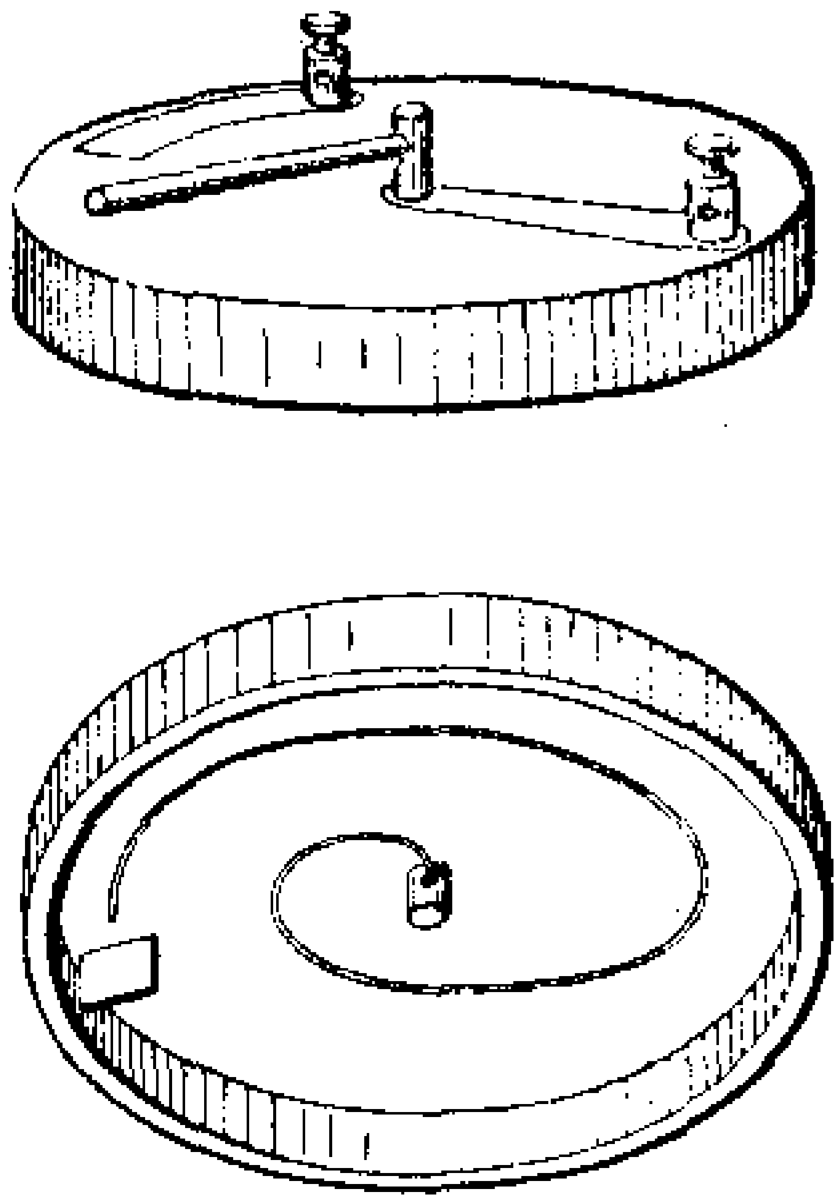

FIG. 17.—Coherer, consisting of a spiral of thin iron wire mounted on an adjustable spindle and an aluminium plate. When the lever is moved clockwise, the tip of the iron wire presses gently against the aluminium plate.

feeble stimuli, is more metrical. If the filings used are coarse, say turnings or borings, the tube approximates to a single coherer ; if they are fine, it has a larger range of sensibility. In every case what these receivers feel are sudden jerks of current ; smooth sinuous vibrations are ineffective. They seem to me to respond best to waves a few inches long, but doubtless that is determined chiefly by the dimensions of some conductor with which they happen to be associated. (Figs. 17 and 18.)

Filings in open, responding to Sphere, to Electrophorus, to Spark, from Gold-leaf Electroscope.

I picture to myself the action as follows: Suppose two fairly clean pieces of metal in light contact—say two pieces of iron—connected to a single voltaic cell; a film of what may be called oxide intervenes between the surfaces, so that only an insignificant current is allowed to pass, because a volt or two is insufficient to break down the insulating film, except perhaps at one or two atoms.* If the film is not permitted to conduct at all, it is not very sensitive; the most sensitive condition is attained when an infinitesimal current passes, strong enough just to show on a moderate galvanometer.

Now let the slightest surging occur, say by reason of a sphere being charged and discharged at a distance of forty yards; the film

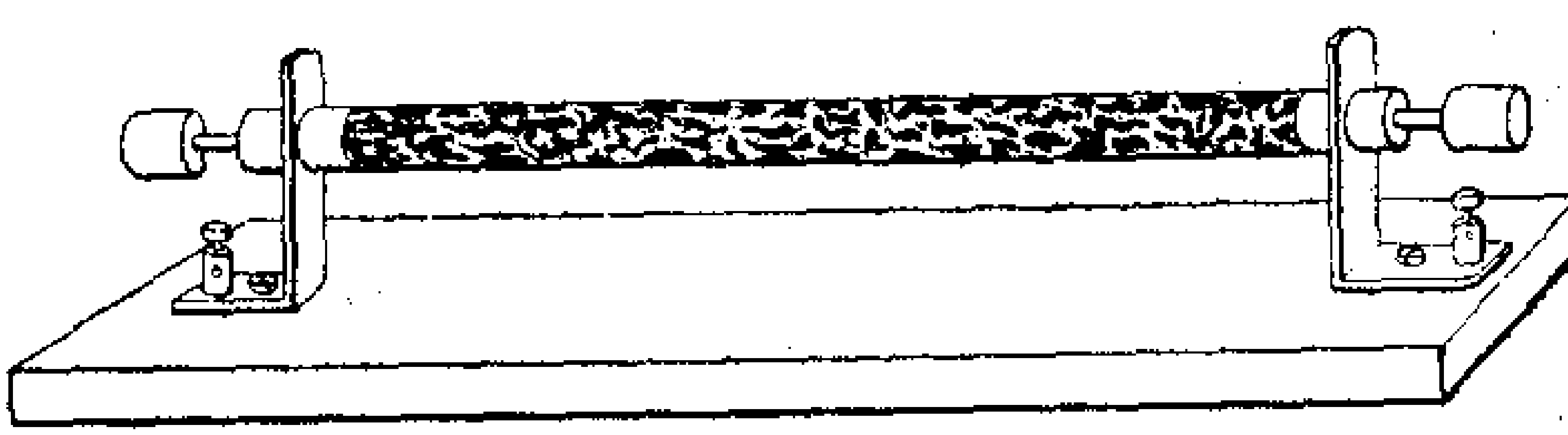

Fig. 18.—Iron Borings Tube, one-third natural size.

at once breaks down--perhaps not completely, that is a question of intensity—but permanently. As I imagine, more molecules get within each other's range, incipient cohesion sets in, and the momentary electric quiver acts somewhat like a flux. It is a singular variety of electric welding. A stronger stimulus enables more molecules to hold on, the process is surprisingly metrical; and, as far as I roughly know at present, the change of resistance is proportional to the energy of the electric radiation, from a source of given frequency.

It is to be specially noted that a battery current is not needed to *effect* the cohesion, only to demonstrate it. The battery can be applied after the spark has occurred, and the resistance will be found changed as much as if the battery had been on all the time.

* See *Phil. Mag.*, Jan., 1894, p. 94.

The incipient cohesion electrically caused can be mechanically destroyed. Sound vibrations, or any other feeble mechanical disturbances, such as scratches or taps, are well adapted to restore the contact to its original high-resistance sensitive condition. The more feeble the electrical disturbance the slighter is the corresponding mechanical stimulus needed for restoration. When working with the radiating sphere (Fig. 19) at a distance of forty yards out of window, I could not for this reason shout to my assistant, to cause him to press the key of the coil and make a spark, but I showed him a duster instead, this being a silent signal which had no disturbing effect on the coherer or tube of filings. I mention 40 yards, because that was one of the first outdoor experiments; but I should think that something more like half an mile was nearer the limit of sensitiveness. However, this is a rash statement not at present verified. At 40 or 60 yards the exciting spark could be distinctly heard, and it was interesting to watch the spot of light begin its long excursion and actually travel a distance of 2in. or 3in. before the sound arrived. This experiment proved definitely enough that the efficient cause travelled quicker than sound, and disposed completely of any sceptical doubts as to sound-waves being, perhaps, the real cause of the phenomenon.

Invariably, when the receiver is in good condition, sound or other mechanical disturbance acts one way, viz., in the direction of increasing resistance, while electrical radiation or jerks act the other way, decreasing it. While getting the receiver into condition, or when it is getting out of order, vibrations and sometimes electric discharges act irregularly; and an occasional good shaking does the filings good. I have taken rough measurements of the resistance, by the simple process of restoring the original galvanometer deflection by adding or removing resistance coils. A half-inch tube 8in. long, of selected iron turnings (Fig. 18) had a resistance of 2,500 ohms in the sensitive state. A feeble stimulus, caused by a distant electrophorus spark, brought it down 400 ohms. A rather stronger one reduced it by 500 and 600, while a trace of spark given to a point of the circuit itself, ran it down 1,400 ohms.

This is only to give an idea of the quantities. I have not yet done any seriously metrical experiments.

DETECTORS OF RADIATION.

Physiological.	Chemical.	Thermal.	Electrical.	Mechanical.	Microphonic.
					Selenium.(?)
Eye.	Photographic Plate.	Thermopile.	Spark. (Hertz.)	Electrometer. (Blyth and Bjerknes.)	Impulsion Cell. (Minchin.)
× Frog's Leg. (Hertz and Ritter.)	Explosive Gases.	Bolometer. (Rubens and Ritter.)	{Telephone; Air-gap and Arc.} (Lodge.)	Suspended Wires. (Hertz and Boys.)	Filings. (Branly.)
	Photoelectric Cell.	Expanding Wire. (Gregory.) Thermal Junction. (Klemencik.)	Vacuum Tube. (Dragoumis.) Galvanometer. (Fitzgerald.) Air-gap and Electroscope. (Boltzmann.) Trigger Tube. (Warburg and Zehnder.)		Coherer. (Hughes and Lodge.)

× The cross against the frog's leg indicates that it does not appear really to respond to radiation, unless stimulated in some secondary manner. The names against the other things are unimportant, but suggest the persons who applied the detector to electric radiation. The interrogation mark against Selenium indicates that its position in the microphonic column may be doubtful.

From the wall diagram which summarises the various detectors, and which was prepared a month or so ago, I see I have omitted selenium, a substance which in certain states is well known to behave to visible light as these other microphonic detectors behave to Hertz waves. It is now inserted, but with a query to indicate that its position in the table is not *certainly* known.

Electrical Theory of Vision.

And I want to suggest that quite possibly the sensitiveness of the eye is of the same kind. As I am not a physiologist I cannot be seriously blamed for making wild and hazardous speculations in that region. I therefore wish to guess that some part of the retina is an electrical organ, say like that of some fishes, maintaining an electromotive force which is prevented from stimulating the nerves solely by an intervening layer of badly conducting material, or of conducting material with gaps in it; but that when light falls upon the retina these gaps become more or less conducting, and the nerves are stimulated. I do not feel clear which part is taken by the rods and cones, and which part by the pigment cells; I must not try to make the hypothesis too definite at present.

If I had to make a demonstration model of the eye on these lines, I should arrange a little battery to excite a frog's nerve-muscle preparation through a circuit completed all except a layer of filings or a single bad contact. Such an arrangement would respond to Hertz waves. Or, if I wanted actual light to act, instead of grosser waves, I would use a layer of selenium.

But the bad contact and the Hertz waves are the most instructive, because we do not at present really know what the selenium is doing, any more than what the retina is doing.

And observe that (to my surprise, I confess) the rough outline of a theory of vision thus suggested is in accordance with some of the principal views of the physiologist Hering. The sensation of light is due to the electrical stimulus; the sensation of black is due to the mechanical or tapping back stimulus. Darkness is physiologically not the mere cessation of light. Both are positive sensations, and both stimuli are necessary; for until the filings are tapped back vision is persistent. In the eye model the period of

mechanical tremor should be, say, $\frac{1}{10}$th second, so as to give the right amount of persistence of impression.

No doubt in the eye the tapping back is done automatically by the tissues, so that it is always ready for a new impression, until fatigued. And by mounting an electric bell or other vibrator on the same board as a tube of filings, it is possible to arrange so that a feeble electric stimulus shall produce a feeble steady effect, a stronger stimulus a stronger effect, and so on; the tremor asserting its predominance, and bringing the spot back whenever the electric stimulus ceases.

An electric bell thus close to the tube is, perhaps, not the best vibrator; clockwork might do better, because the bell contains in itself a jerky current, which produces one effect, and a mechanical vibration, which produces an opposite effect; hence the spot of light can hardly keep still. By lessening the vibration—say, by detaching the bell from actual contact with the board, the electric jerks of the intermittent current drive the spot violently up the scale; mechanical tremor brings it down again.

You observe that the eye on this hypothesis is, in electrometer language, heterostatic. The energy of vision is supplied by the organism; the light only pulls a trigger. Whereas the organ of hearing is idiostatic. I might draw further analogies between this arrangement and the eye, *e.g.*, about the effect of blows or disorder causing irregular conduction and stimulation, of the galvanometer in the one instrument, of the brain cells in the other.

A handy portable exciter of electric waves is one of the ordinary hand electric gas-lighters, containing a small revolving doubler—*i.e.*, an inductive or replenishing machine. A coherer can feel a gas-lighter across a lecture theatre. Minchin often used them for stimulating his impulsion cells. I find that when held near they act a little even when no ordinary spark occurs, plainly because of the little incipient sparks at the brushes or tinfoil contacts inside. A Voss machine acts similarly, giving a small deflection whil[e] working up before it sparks.

Holtz Sparks not exciting Tube: except by help of a polished knob.

And notice here that our model eye has a well-defined range [of] vision. It cannot see waves too long for it. The powerful di[...]

turbance caused by the violent flashes of a Wimshurst or Voss machine it is blind to. If the knobs of the machine are well polished it will respond to some high harmonics, due to vibrations in the terminal rods; and these are the vibrations to which it responds when excited simply by an induction-coil. The coil should have knobs instead of points. Sparks from points or dirty knobs hardly excite the coherer at all. But hold a well-polished sphere or third knob between even the dirty knobs of a Voss machine, and the coherer responds at once to the surgings got up in it.

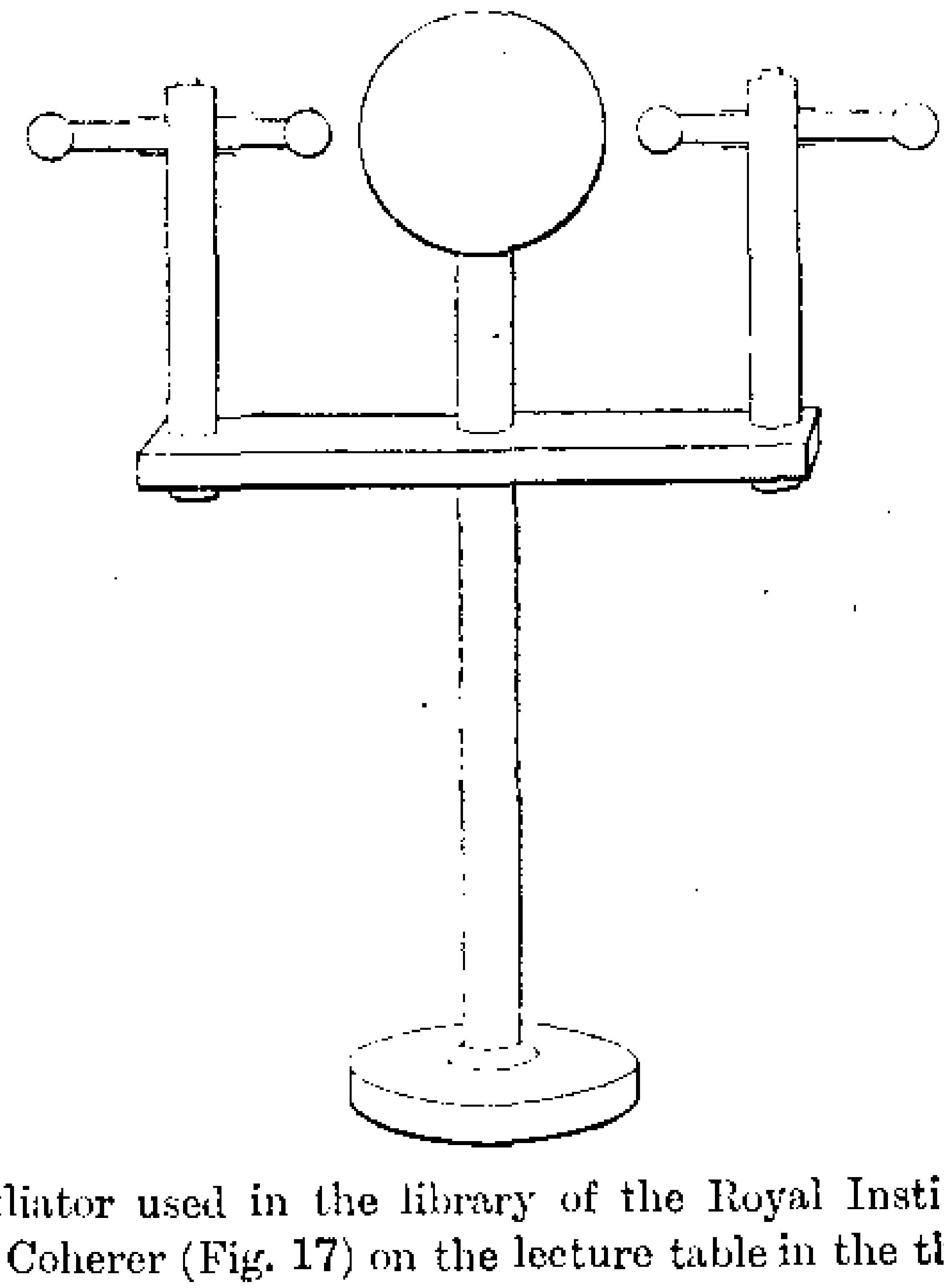

FIG. 19.—Radiator used in the library of the Royal Institution, exciting the Coherer (Fig. 17) on the lecture table in the theatre.

Feeble short sparks again are often more powerful exciters than are strong long ones. I suppose because they are more sudden.

This is instructively shown with an electrophorus lid. Spark it to a knuckle, and it does very little. Spark it to a knob and it works well. But now spark it to an insulated sphere, there is some effect. Discharge the sphere, and take a second spark, without recharging the lid; do this several times; and at last, when

the spark is inaudible, invisible, and otherwise imperceptible, the coherer some yards away responds more violently than ever, and the spot of light rushes from the scale.

If a coherer be attached by a side wire to the gas pipes, and an electrophorus spark be given to either the gas pipes or the water pipes or even to the hot-water system in any other room of the building, the coherer responds.

In fact, when thus connected to gas-pipes one day when I tried it, the spot of light could hardly keep five seconds still. Whether there was a distant thunderstorm, or whether it was only picking up telegraphic jerks, I do not know. The jerk of turning on or off an extra Swan lamp can affect it when sensitive. I hope to try for long-wave radiation from the sun, filtering out the ordinary well-known waves by a black-board or other sufficiently opaque substance.

We can easily see the detector respond to a distant source of radiation now, viz., to a 5in. sphere placed in the library between secondary coil knobs; separated from the receiver, therefore, by several walls and some heavily gilded paper, as well as by 20 or 30 yards of space.

Also I exhibit a small complete detector made by my assistant, Mr. Davies, which is quite portable and easily set up. The essentials (battery, galvanometer, and coherer) are all in a copper cylinder three inches by two. A bit of wire a few inches long, pegged into it, helps it to collect waves. It is just conceivable that at some distant date, say by dint of inserting gold wires or powder in the retina, we may be enabled to see waves which at present we are blind to.

Observe how simple the production and detection of Hertz waves are now. An electrophorus or a frictional machine serves to excite them; a voltaic cell, a rough galvanometer, and a bad contact serves to detect them. Indeed, they might have been observed at the beginning of the century, before galvanometers were known. A frog's leg or an iodide of starch paper would do almost as well.

A bad contact was at one time regarded as a simple nuisance, because of the singularly uncertain and capricious character of the current transmitted by it. Hughes *observed its sensitiveness to* sound-waves, and it became the microphone. Now it turns out

to be sensitive to electric waves, if it be made of any oxidisable metal (not of carbon),* and we have an instrument which might be called a micro-something, but which, as it appears to act by cohesion, I call at present a coherer. Perhaps some of the capriciousness of an anathematised bad contact was sometimes due to the fact that it was responding to stray electric radiation.

The breaking down of cohesion by mechanical tremor is an ancient process, observed on a large scale by engineers in railway axles and girders; indeed, the cutting of small girders by persistent blows of hammer and chisel reminded me the other day of the tapping back of our cohering surfaces after they have been exposed to the welding effect of an electric jerk.

Receiver in Metal Enclosure.

If a coherer is shut up in a complete metallic enclosure, waves cannot get at it, but if wires are led from it to an outside ordinary galvanometer, it remains nearly as sensitive as it was before (nearly, not quite), for the circuit picks up the waves and they run along the insulated wires into the closed box. To screen it effectively, it is necessary to enclose battery and galvanometer and every bit of wire connection; the only thing that may be left outside is the needle of the galvanometer. Accordingly, here we have a compact arrangement of battery and coil and coherer, all shut up in a copper box (Fig. 21). The coil is fixed against the side of the box at such height that it can act conveniently on an outside suspended compass needle. The slow action of the coil has no difficulty in getting through copper, as everyone knows; only a perfect conductor could screen off that, but the Hertz waves are effectively kept out by sheet copper.

It must be said, however, that the box must be exceedingly well closed for the screening to be perfect. The very narrowest chink permits their entrance, and at one time I thought I should have to

* Fitzgerald tells me that he has succeeded with carbon also. My experience is that the less oxidisable the metal, the more sensitive and also the more troublesome is the detector. Mr. Robinson has now made me a hydrogen vacuum tube of brass filings, which beats the coherer for sensitiveness. July, 1894. Prof. Elihu Thomson and Prof. E. Houston have noticed similar effects in electrical and engineering practice. See a letter by Prof. E. Thomson in *The Electrician*, July 13, 1894, Vol. XXXIII., p. 304.

solder a lid on before they could be kept entirely out. Clamping a copper lid on to a flange in six places was not enough. But by the use of pads of tinfoil, chinks can be avoided, and the inside of the box becomes then electrically dark.

If even an inch of the circuit protrudes, it at once becomes slightly sensitive again; and if a mere single wire protrudes through the box, provided it is insulated where it passes through, the waves will utilise it as a speaking tube, and run blithely in. And this whether the wire be connected to anything inside or not, though it acts more strongly when connected.

In careful experiments, where the galvanometer is protected in one copper box and the coherer in another, the wires connecting

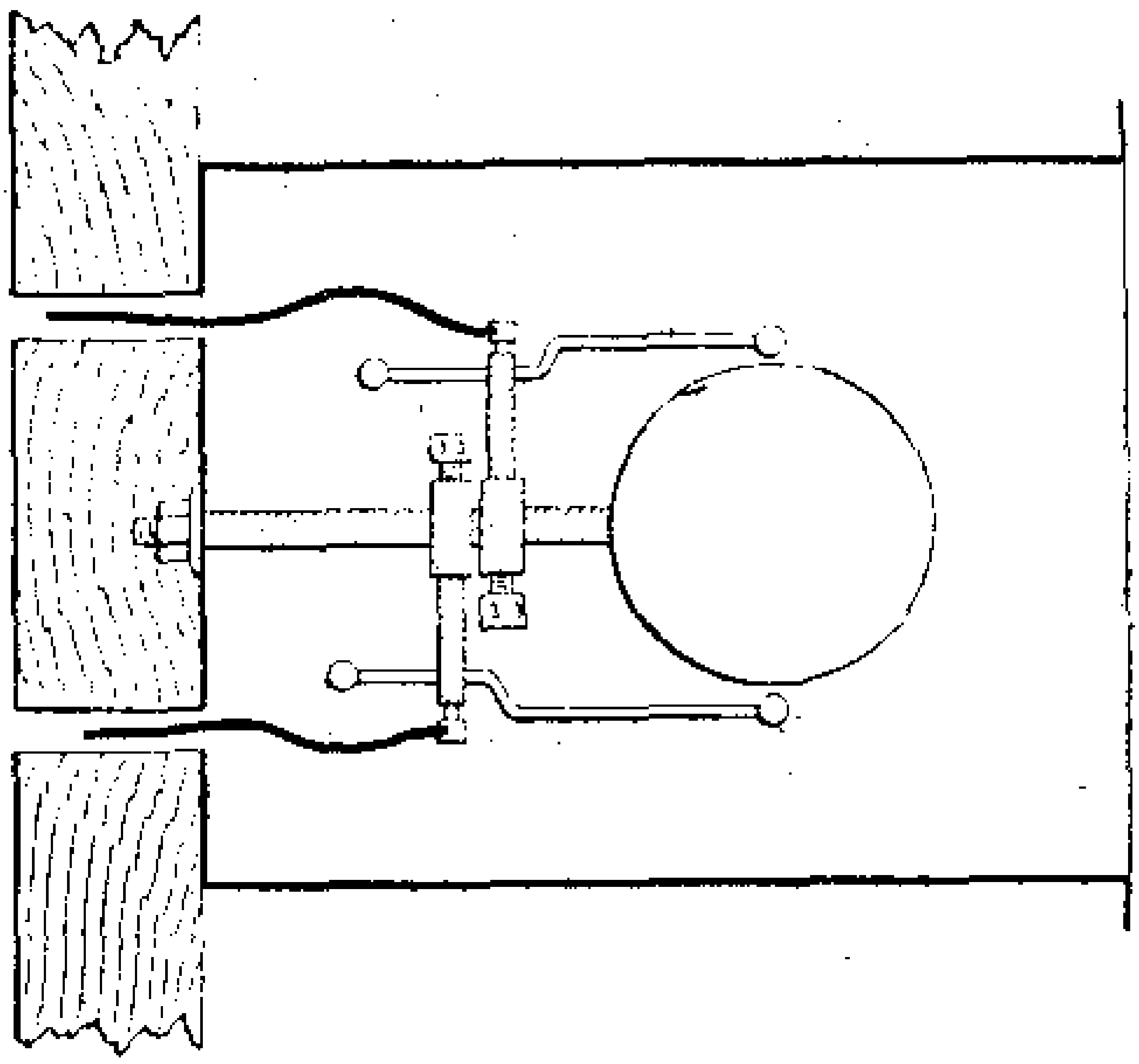

FIG. 20.—Spherical Radiator for emitting a Horizontal Beam arranged inside a Copper Hat, fixed against the outside of a metal-lined Box. One eighth natural size. The wires pass into the box through glass tubes not shown.

the two must be encased in a metal tube (Fig. 21), and this tube must be well connected with the metal of both enclosures, if nothing is to get in but what is wanted.

Similarly, when definite radiation is desired, it is well to put the radiator in a copper hat, open in only one direction. And in order to guard against reflected and collateral surgings running along the wires which pass outside to the exciting coil and battery, as they are liable to do, I am accustomed to put all these things in a

packing case lined with tinfoil, to the outside of which the sending hat is fixed, and to pull the key of the primary exciting circuit by a string from outside.

Even then, with the lid of the hat well clamped on, something gets out, but it is not enough to cause serious disturbance of qualitative results. The sender must evidently be thought of as emitting a momentary blaze of light which escapes through every chink. Or, indeed, since the waves are some inches long, the difficulty of keeping them out of an enclosure may be likened to the difficulty of excluding sound; though the difficulty is not quite so great as that, since a reasonable thickness of metal is really opaque. I fancied once or twice I detected a trace of transparency in such metal sheets as ordinary tinplate, but unnoticed chinks elsewhere may have deceived me. It is a thing easy to make sure of as soon as I have more time.

One thing in this connection is noticeable, and that is how little radiation gets either in or out of a small round hole. A narrow long chink in the receiver box lets in a lot; a round hole the size of a shilling lets in hardly any, unless indeed a bit of insulated wire protrudes through it like a collecting ear trumpet.

It may be asked how the waves get out of the metal tube of an electric gas-lighter. But they do not; they get out through the handle, which being of ebonite is transparent. Wrap up the handle tightly in tinfoil, and a gas-lighter is powerless.

Optical Experiments.

And now in conclusion I will show some of the ordinary optical experiments with Hertz waves, using as source either one of two devices; either a 5in. sphere with sparks to ends of a diameter (Fig. 19), an arrangement which emits 7in. waves but of so dead-beat a character that it is wise to enclose it in a copper hat to prolong them and send them out in the desired direction; or else a 2in. hollow cylinder with spark knobs at ends of an internal diameter (Fig. 12). This last emits 3in. waves of a very fairly persistent character, but with nothing like the intensity of one of the outside radiators.

As receiver there is no need to use anything sensitive, so I employ a glass tube full of coarse iron filings, put at the back of

a copper hat with its mouth turned well askew to the source, which is put outside the door at a distance of some yards, so that only a little direct radiation can reach the tube. Sometimes the tube is put lengthways in the hat instead of crossways, which makes it less sensitive, and has also the advantage of doing away with the polarising, or rather analysing, power of a crossway tube.

The radiation from the sphere is still too strong, but it can be stopped down by a diaphragm plate with holes in it of varying size clamped on the sending hat (Fig. 21).

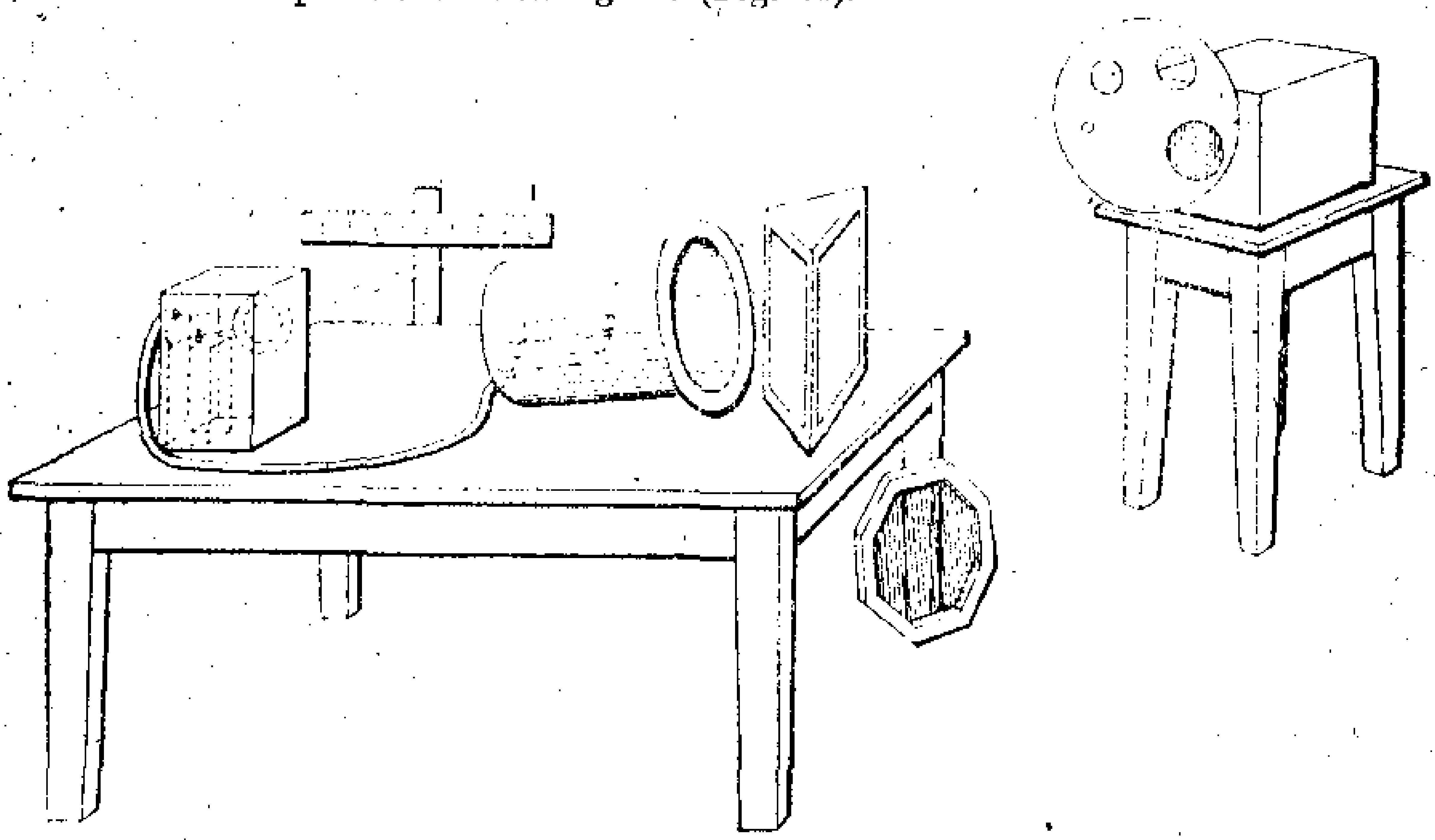

FIG. 21.—General arrangement of experiments with the Copper "Hat," showing Metal Box on a Stool, inside which the Radiators were fixed; the Copper Hat containing the Coherer, with the Metal Box containing Battery and Galvanometer Coil connected to it by a compo pipe conveying the wires; a Paraffin Prism; and a Polarising Grid.

Reflection.

Having thus reduced the excursion of the spot of light to a foot or so, a metal plate is held as reflector, and at once the spot travels a couple of yards. A wet cloth reflects something, but a thin glass plate, if dry, reflects next to nothing, being, as is well known, too thin to give anything but "the black spot." I have fancied that it reflects something of the 3in. waves.

With reference to the reflecting power of different substances it may be interesting to give the following numbers, showing the motion of the spot of light when 8in. waves were reflected into the copper hat, the angle of incidence being about 45deg., by the following mirrors :—

Sheet of window glass....................	0 or at most 1 division.
Human body................................	7 divisions.
Drawing board.............................	12 ,,
Towel soaked with tap-water...........	12 ,,
Tea-paper (lead ?).........................	40 ,,
Dutch metal paper	70 ,,
Tinfoil	80 ,,
Sheet copper.................................	100 and up against stops.

Refracting Prism and Lens.

A block of paraffin about a cubic foot in volume is cast into the shape of a prism with angles 75deg., 60deg., and 45deg. Using the large angle, the rays are refracted into the receiving hat (Fig. 21), and produce an effect much larger than when the prism is removed.

An ordinary 9in. glass lens is next placed near the source, and by means of the light of a taper it is focussed between source and receiver. The lens is seen to increase the effect by concentrating the electric radiation.

Arago Disc; Grating; and Zone-plate.

The lens helps us to set correctly an 18in. circular copper disc in position for showing the bright diffraction spot. Removing the disc the effect is much the same as when it was present; in accordance with the theory of Poisson. Add the lens and the effect is greater. With a diffraction grating of copper strips 2in. broad and 2in. apart, I have not yet succeeded in getting good results. It is difficult to get sharp nodes and interference effects with these sensitive detectors in a room. I expect to do better when I can try out of doors away from so many reflecting surfaces; indoors it is like trying delicate optical experiments in a small whitewashed chamber well supplied with looking-glasses; nor have I ever succeeded in getting clear concentration with this zone-

plate having Newton's rings fixed to it in tinfoil. But really there is nothing of much interest now in diffraction effects except the demonstration of the waves and the measure of their length. There was immense interest in Hertz's time, because then the wave character of the radiation had to be proved; but every possible kind of wave must give interference and diffraction effects, and their theory is, so to say, worked out. More interest attaches to polarisation, double refraction, and dispersion experiments.

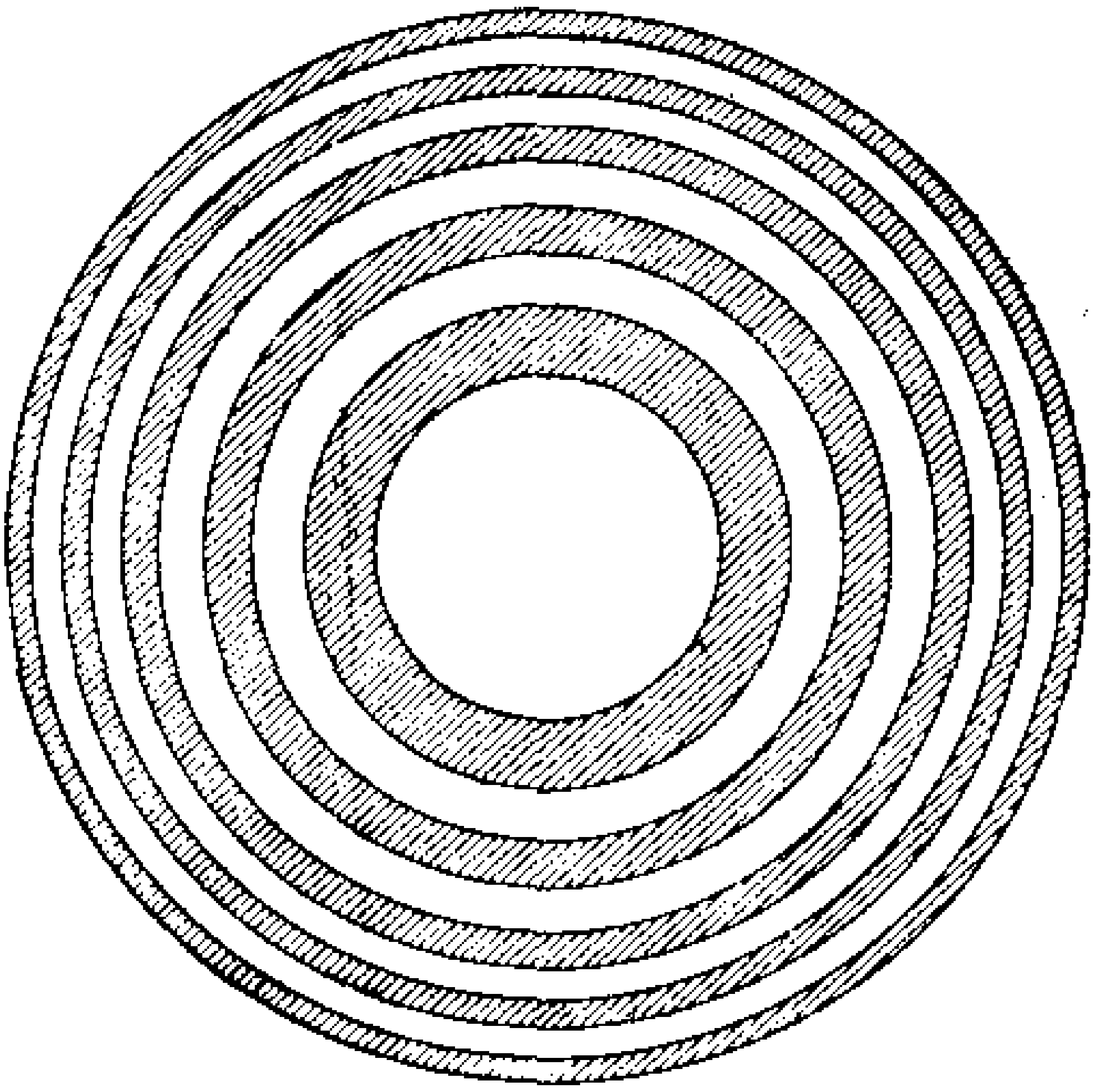

FIG. 22.—Zoneplate of Tinfoil on Glass. Every circular strip is of area equal to central space.

Polarising and Analysing Grids.

Polarisation experiments are easy enough. Radiation from a sphere is already strongly polarised, and the tube acts as a partial analyser, responding much more vigorously when its length is parallel to the line of sparks than when they are crossed; but a convenient extra polariser is a grid of wires something like what was used by Hertz, only on a much smaller scale; say an 18in. octagonal frame of copper strip with a harp of parallel copper wires (*see* Fig. 21, on floor). The spark-line of the radiator being set at 45deg., a vertical grid placed over receiver reduces the deflection to about one-half, and a crossed grid over the source reduces it to nearly nothing.

Rotating either grid a little, rapidly increases the effect, which becomes a maximum when they are parallel. The interposition of a third grid, with its wires at 45deg. between two crossed grids, restores some of the obliterated effect.

Radiation reflected from a grid is strongly polarised, of course, in a plane normal to that of the radiation which gets through it. They are thus analogous in their effect to Nicols, or to a pile of plates.

The electric vibrations which get through these grids are at right angles to the wires. Vibrations parallel to the wires are reflected or absorbed.

Reflecting Paraffin Surface; Direction of Vibrations in Polarised Light.

To demonstrate that the so-called plane of polarisation of the radiation transmitted by a grid is at right angles to the electric vibration,* *i.e.*, that when light is reflected from the boundary of a transparent substance at the polarising angle the electric vibrations of the reflected beam are perpendicular to the plane of reflection, I use the same paraffin prism as before; but this time I use its largest face as a reflector, and set it at something near the polarising angle. When the line of wires of the grid over the mouth of the emitter is parallel to the plane of incidence, in which case the electric vibrations are perpendicular to the plane of incidence, plenty of radiation is reflected by the paraffin face. Turning the grid so that the electric vibrations are in the plane of incidence, we find that the paraffin surface set at the proper angle is able to reflect hardly anything. In other words, the vibrations contemplated by Fresnel are the electric vibrations; those dealt with by McCullagh are the magnetic ones.

Thus are some of the surmises of genius verified and made obvious to the wayfaring man.

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* *Cf.* Trouton, in *Nature*, Vol. 39, p. 393; and many optical experiments by Mr. Trouton, Vol. 40, p. 398.

NOTE.

It may be well to explain that in my Royal Institution lecture I made no reference to the transmission of waves along *wires*. I regard the transmission of waves in *free space* as the special discovery of Hertz. Their transmission along wires is a much older thing, Von Bezold saw them in 1870, and I myself got quantitative evidence of nodes and loops in wires when working with Mr. Chattock in the session 1887-8 (*see*, for instance, contemporary reports of the Bath Meeting of the British Association, 1888, in *The Electrician*), and I exhibited them some time afterwards to the Physical Society, the wires themselves becoming momentarily luminous at every discharge except at the nodes :—

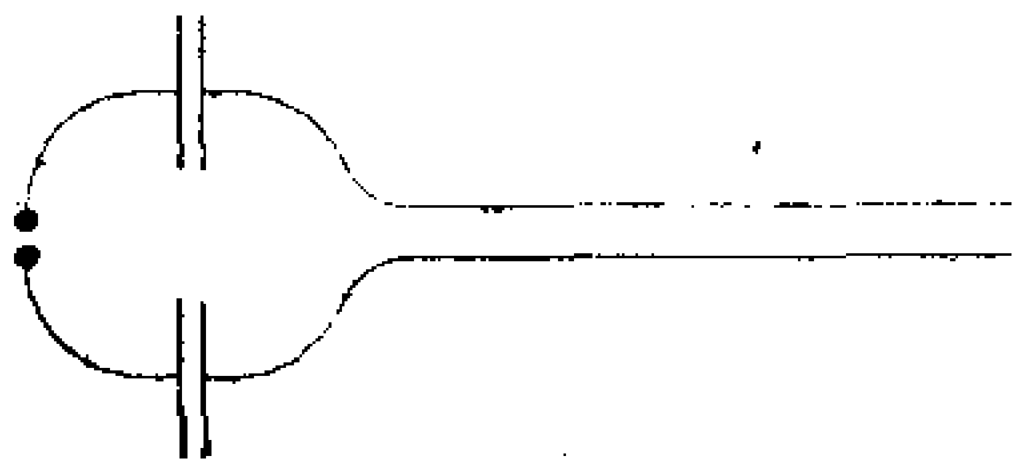

FIG. 23.

It may be worth mentioning that the arrangement frequently referred to in Germany by the name of Lecher (viz., that shown in the figure), and on which a great number of experiments have been made, is nothing but a pair of Leyden jars with long wires leading from their outer coats. The use of air dielectric instead of glass permits the capacity to be adjusted, and also readily enables the capacity to be small, and the frequency, therefore, high; but otherwise the arrangement is the same in principle as had frequently been used by myself in the series of experiments called "the recoil kick." For these and other reasons no reference has been made in my lecture to the excellent work done on wires by Sarasin and De la Rive; nor to work done by Lecher, Rubens, Arons, Paalzow, Ritter, Blondlot, Curie, D. E. Jones, Yule, Barton, and other experimenters.

Appendices.

APPENDIX I.

ON THE DISELECTRIFICATION OF METALS AND OTHER BODIES BY LIGHT.

Referring to a footnote to my Royal Institution lecture on page 12, Messrs. Elster and Geitel have been good enough to call my attention to a great deal of work done by them in the same direction. To make amends for my ignorance of this work at the time of my Royal Institution lecture, and to make it better known in this country, I make abstract of their Papers as follows :—

Wiedemann's Annalen, 38, p. 40.—"On the Dissipation of Negative Electricity by Sun and Daylight."

With a view to Arrhenius' theory concerning atmospheric electricity, we arranged experiments on the photo-electric power of sunlight and diffuse daylight at Wolfenbüttel from the middle of May to the middle of June, 1889. Hoor alone had observed the effect of sunlight; other experimenters had failed to find it, but we find a discharging effect even in diffuse daylight.

We take an insulated zinc dish, 20 cm. diameter, connect it to a quadrant electrometer or an Exner's electroscope, and expose it in the open so that it can be darkened or illuminated at pleasure. Sunlight makes it lose a negative charge of 300 volts in about 60 seconds. A positive charge of 300 volts is retained. The dissipation of negative electricity ceases in the dark, and is much weakened by the interposition of glass. But light from the blue sky has a distinct effect. Fill the dish with water, or stretch a damp cloth over it, and the action stops. A freshly-scrubbed plate acquires a positive charge of $2\frac{1}{2}$ volts, which can be increased by blowing.

With freshly-cleansed wires of zinc, aluminium, or magnesium attached to the knob of the electroscope, a permanent negative charge is impossible in open sunlight. Indeed, magnesium shows a dissipating action in diffuse evening light. Such wires act like glowing bodies. Exposing an electroscope so provided in an open space it acquires a positive charge from the atmosphere. No abnormal dissipation of positive electricity has been observed.*

Wied. Ann., 38, p. 497.—Continuation of Same Subject.

Our success last time was largely due to the great clearness of the sky in June, and we wished to see if we could get the same effect at the beginning of the winter.

The following is our summary of results :

Bright fresh surfaces of the metals zinc, aluminium, magnesium were discharged by both sun and daylight when they were negatively charged ; and they spontaneously acquired a positive charge, whose amount could be increased by blowing.† A still more notable sensitiveness to light is shown by the amalgams of certain metals, viz., in the order of their sensitiveness, K, Na, Zn, Sn. Since pure mercury shows no effect, the hypothesis is permisssible that the active agent is the metal dissolved in the mercury. If so, the following are the most active metals :—

K, Na, (Mg, Al), Zn, Sn.

All other metals tried, such as Sn, Cd, Pb, Cu, Fe, Hg, Pt, and gas carbon, show no action. The same is true of nearly all non-metallic bodies ; but one of them—namely, the powder of *Balmain's luminous paint*—acted remarkably well in sunlight. Of liquids, hot and cold water, and hot and cold salt solution were completely inactive ; consequently, wetting the surfaces of metals destroys their sensibility to light.

The illumination experiments can be arranged in either of two ways. For experiments in free space we use zinc, aluminium, or magnesium wires, or small amalgamated spheres of zinc provided with an iron rod. With these it can be easily shown that the illuminated surface of certain metals acts in the same way as a flame-collector.

* This last statement does not agree with my observations.—O. J. L.

† A fact noticed by Bichat and Blondlot.

For demonstration experiments the apparatus described* is better, and with this we show the following :—

Amalgamated zinc, negatively charged, discharges almost instantly in sunlight; and if near a positively-electrified body charges itself positively.

The same thing happens, though more slowly, in diffuse daylight. Red glass stops the action, but the following let some through :— Selenite, mica, window glass, blue (cobalt) glass.

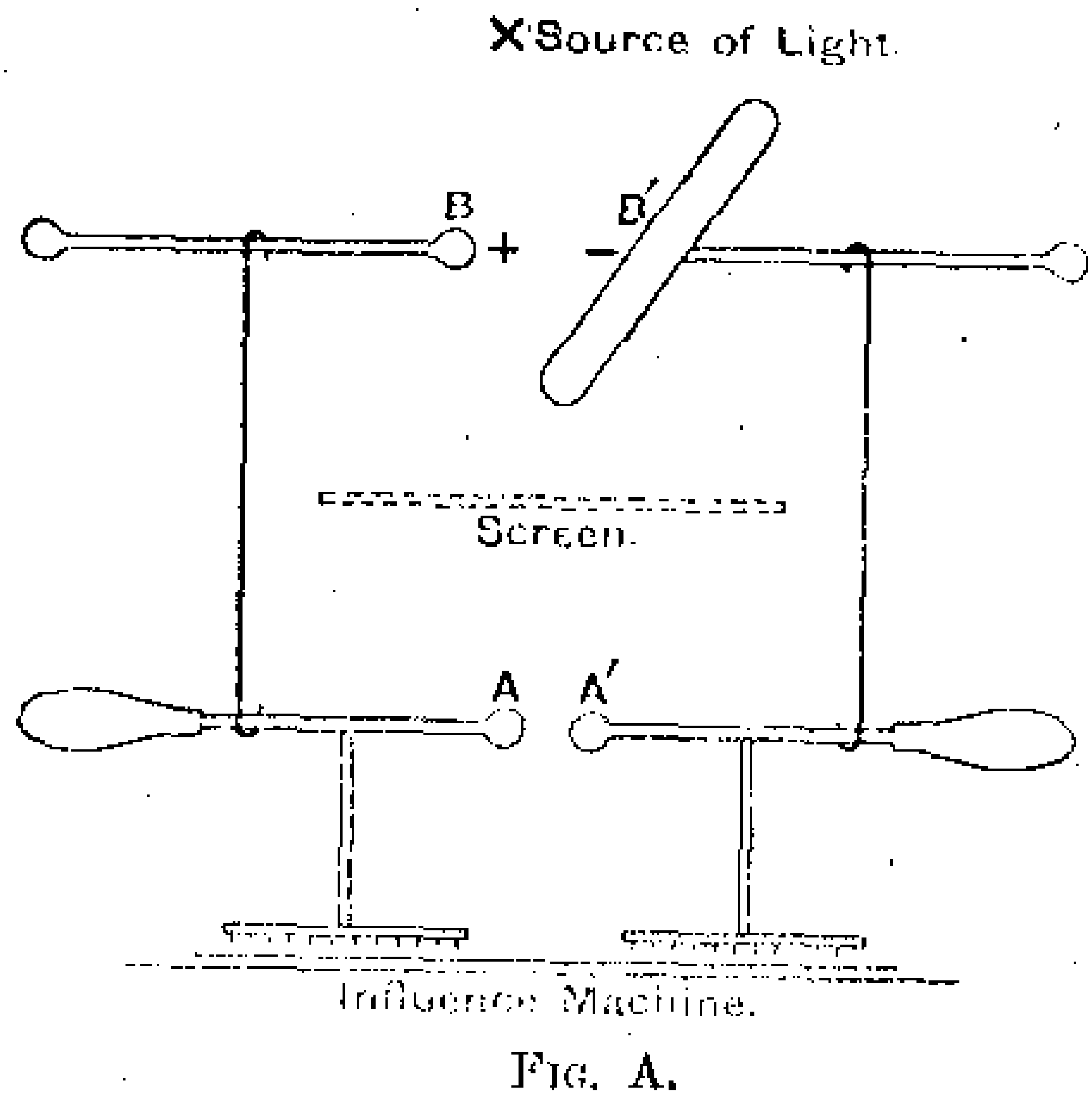

FIG. A.

Explanation of Fig. A.—B′ is a brightly polished amalgamated zinc plate attached to the negative pole of a Holtz machine, with the positive knob from 6 to 10 centimetres distant. The source of light is a strip of burning magnesium ribbon 30 to 50 centimetres away. Whenever the spark is able just to choose the path B B′, light shining on the zinc plate checks it and transfers the spark to A A′.

Wied. Ann., 39, p. 332.—On a Checking Action of Illumination on Electric Spark and Brush Discharge.

If sparks are just able to occur between a brass knob and a clean amalgamated zinc cathode, illumination of the latter by ultra-

* In this apparatus the mercury amalgams of K and Na are run through a fine funnel, so that the freshly-formed surface of the drops may be illuminated. Under these circumstances, while pure mercury fell from —185 to —175 volts in 30sec., amalgam of zinc fell from — 195 to — 116 in 15sec., amalgam of sodium fell from — 195 to 0 in 10sec., and an amalgam of potassium fell from —195 to 0 in 5 seconds.

violet light tends to check them. [This is a curious inversion of Hertz's fundamental experiment on the subject. It is an effect I have not yet observed; but Elster and Geitel's arrangement differs from mine* in that the surfaces are at a steady high potential before the spark, so that light can exert its discharging influence, whereas in mine the surfaces were at zero potential until the spark-rush occurred. Hertz's arrangement was more like mine, inasmuch as he illuminated the knobs of an induction coil on the verge of sparking. It appears, then, that whereas the action of light in discharging negative electricity from clean oxidisable metallic surfaces is definite enough, its influence on a spark discharge differs according to the conditions of that discharge—in cases of "steady strain" it tends to hinder the spark; in cases of "sudden rush" it tends to assist it.†—O. J. L.]

Wied. Ann., *41*, *p. 161.*—*On the Use of Sodium-Amalgam in Photo-electric Experiments.*

Elster and Geitel have repeated some of Righi's experiments on the discharge of negative electricity from metals in rarefied air, and find, in agreement with him, that a reduction of pressure to about one millimetre increases the discharge velocity about six or seven times. They proceed to try sodium-amalgam exposed to daylight in exhausted tubes, and describe apparatus for the purpose. Such an arrangement simply cannot hold a negative charge in bright daylight, even although it be unprovided with quartz windows. Even paraffin lamps and sodium flames exert some action.

They observe that under the action of light the boundary surface of the metal and glass changes, and the metal begins to cling to the glass. They suppose that Warburg's vacuum tubes of pure sodium may behave similarly, and show photo-electric sensibility.

The Same, p. 166.—*On a Checking Action of Magnetism on Photo-electric Discharge in Rarefied Gases.*

The authors point out analogies between the above effects and those they had observed in the action of glowing bodies in air, and they mention Lenard and Wolf's experiment's (*Wied. Ann.*

* *See* Fig. 7, page 10.

† There is some truth in this, but the complete matter turns out less simple than that.

XXXVII., p. 443), tending to show that the effect is due to a disintegrating or evaporative effect of light on surfaces. Elster and Geitel had observed that the discharging power of glowing bodies was diminished by application of a magnetic field, the effect being the same as if the temperature was lowered; and they proceed to try if the discharge of negative electricity from illuminated surfaces *in highly-rarefied gas could also be checked or hindered by a magnetic field.* They find that it can.

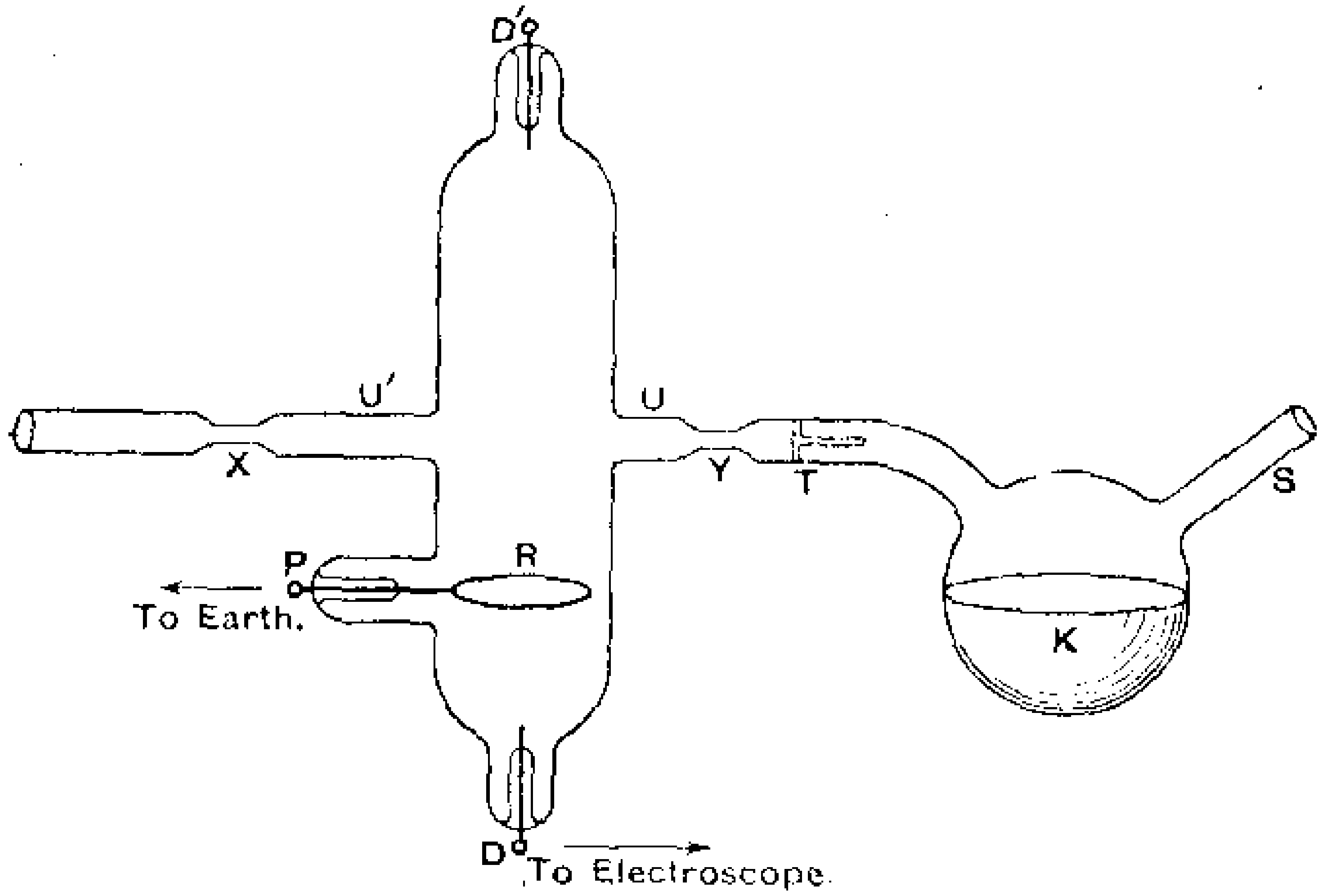

FIG. B.

Explanation of Fig. B.—The sodium and mercury are introduced through the tube S into the globe K. The tube S is then closed, a pump applied to X, and exhaustion carried on for some days. T is an open funnel sealed into the tube (as is done in some vacuum tubes made by Holtz to show a curious unilateral conductivity of rarefied gas. The object of this funnel is to permit metal from the interior, free from scum, to be introduced from K to D when the whole is tilted. Thus a bright surface is exposed to the earth ring R. It can be charged negatively, and its leak under illumination be measured, through the terminal *D*. Sometimes the tube is inverted, so that the active surface may be at D′, further from the earth wire.

Using the light from sparks admitted through a quartz window into the vacuum tube when a negatively-charged amalgamated zinc surface was exposed near an earth-connected platinum ring, and between the poles of a small electro-magnet, they found that when the tube was full of air at 10mm. pressure the magnet had but

little effect, but that at 0·15mm., whereas without the magnet the charge of -270 volts disappeared completely in five seconds, when the magnet was excited it only fell about half that amount in the same time. With hydrogen at 0·24mm. the result was much the same, and at either greater or less pressure in both cases the magnet had less effect. In oxygen the loss of charge was not quite so rapid; and, again, at a pressure of 0·1mm, the magnet more than halved the rate. But in CO_2 the rapidity of loss was

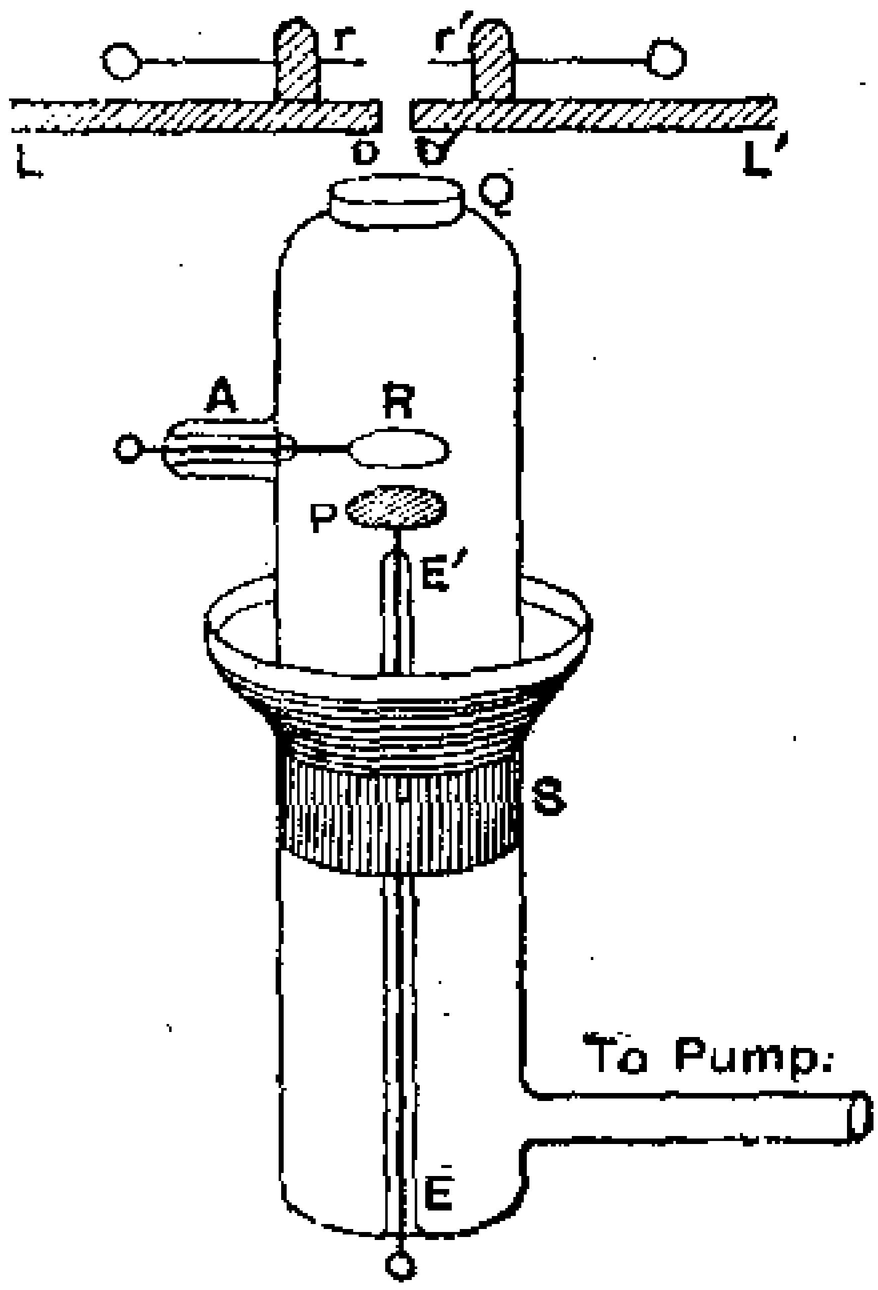

FIG. C.

Explanation of Fig. C.—P is the plate of amalgamated zinc, and R is the earth ring, as before. Ultra-violet light is introduced through a quartz window Q from a spark gap r. The vessel has a joint at the middle, so that the sensitive plate can be got at and changed. Magnet poles are applied outside this vessel in various positions.

extreme.* Either at 1·1mm. or at 0·005mm. the charge of -270 volts leaked away completely in two seconds when the magnet was not excited; but in the latter case (low pressure) exciting the magnet reduced the speed by about one-half. At the pressure of 1·1mm. the magnet did not seem to produce an effect. With daylight the results are similar.

* Corresponding to the activity of this gas as found by Wiedmann and Ebert (*Wied. Ann.*, XXXIII., p. 258), in their researches on the influence of light on ease of sparking.

The authors then discuss the meaning of this result, and its bearing on the opposition hypotheses of Lenard and Wolf and of Righi. Lenard and Wolf's view is that the loss of negative electricity is due to dust disintegrated from the surface by the action of light, but whose existence they consider is established by an observed effect on steam jets. Righi, on the other hand, believes that gas molecules themselves act the part of electric carriers. Elster and Geitel consider that the magnetic effect observed by them supports this latter view, it being known that a magnet acts on currents through gases; and they surmise that the impact of light vibrations may directly assist electric interchange between a gas molecule and the surface, by setting up in them *syntonic stationary vibrations*, something like resonant Leyden jars. It is to be remembered that phosphorescent substances, such as Balmain's paint powder, exhibit marked photo-electric effect in daylight.

The unilateral character of the electric motion, and the charging of neutral surfaces by light, require special hypotheses, concerning an E.M.F. at the boundary of gases and conductors, such as Schuster and Lehmann have made.

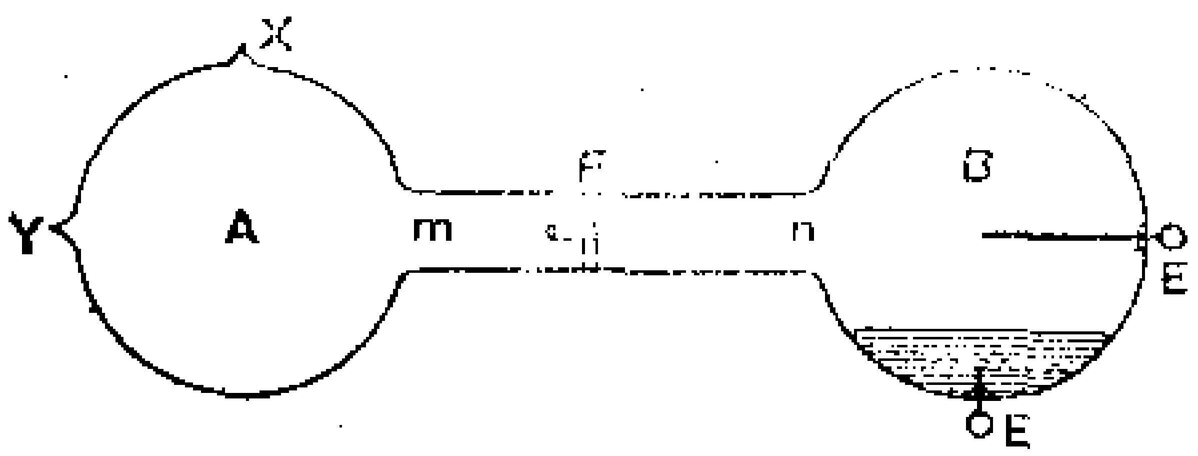

FIG. D.

Explanation of Fig. D.—A simpler arrangement, like the one above (Fig. C), whereby clean liquid alkali metals can be introduced into the experimental chamber B, from the preliminary chamber A, through a cleansing funnel F which dips its beak into the interior.

Wied. Ann. 42, p. 564.—Note on a New Form of Apparatus for Demonstrating the Photo-electric Discharging Action of Daylight.

A vacuum tube suitable for experiments with sodium amalgam or pure sodium, or the liquid sodium-potassium alloy, is described, with the aid of which a current (shown by the charge of an electroscope) can be maintained by a dry pile through the rarefied gas above the metal when it is illuminated from ordinary windows.

Wied. Ann. 43, p. 225.—On the Dependence of the Discharging Action of Light on the Nature of the Illuminated Surface.

Experiments also on differently-coloured lights. Summary of results. The photo-electrically active metals arrange themselves in the following order—Pure K, alloys of K and Na, pure Na. Amalgams of Rb, K, Na, Li, Mg, (Tl, Zn); the same as their voltaic order. With the most sensitive term of the series a candle six metres off can be detected, and the region of spectral red is not inactive. The later terms of the series demand smaller waves, and even for potassium blue light gives a much greater effect than red. No discharge of positive electricity is observable with these substances.

Wied. Ann. 44, p. 722.—On the Dissipation of Electric Charge from Mineral Surfaces by Sunlight.

Hitherto only Balmain's paint powder has been observed to be active among non-metallic substances. Now they try other phosphorescent bodies, and arrive at the following results :—

Fluor-spar is conspicuously photo-electric, both in sunlight and daylight, especially the variety of fluorite called *stinkfluss.*

Freshly-broken surfaces discharge much more rapidly than old surfaces.

Blue waves, and not alone the ultra-violet, have a perceptible effect on fluor-spar.

In a vacuum the mineral loses its photo-electric sensibility and its conductivity too. Contact with damp air restores its sensibility. Moistening with water weakens, but does not destroy, the sensitiveness. On the other hand, igniting the mineral destroys both its photo-electric power and its exceptional phosphorescent property.

Distinct traces of photo-electric power are shown by the following minerals also: Cryolite, heavy spar, celestine, arragonite, strontianite, calcspar, felspar, and granite.

The hypothesis that the power of phosphorescing when illuminated is approximately a measure of the discharging power of light has been verified in many cases; the exceptions can probably be explained by the influence which the electrical conductivity of the illuminated substance exerts on the rate of discharge of

electricity from its surface. This agreement confirms the view expressed by us on the occasion of experiments with Balmain's paint, that, during electrical discharge by light, actions take place which are analogous to those of resonance. Messrs. Wiedemann and Ebert had previously been led by other considerations to the same conclusion.

We are compelled by the results of the present experiments to conclude that a more rapid discharge of electricity into the atmosphere takes place in sunlight than in darkness from the surfaces of

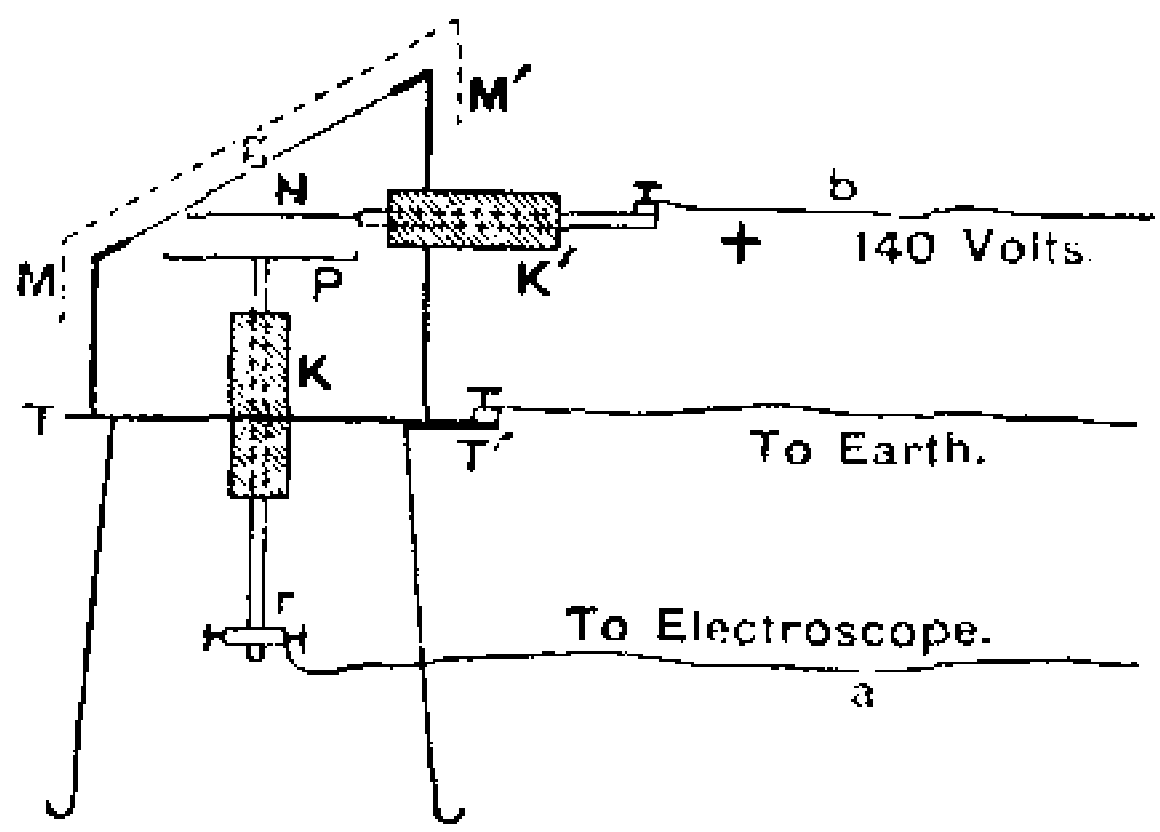

FIG. E.

Explanation of Fig. E.—Arrangement used by Elster and Geitel for exposing various phosphorescent minerals to daylight, while under inductive charge. They were put in powder in the tray P, and the transparent wire-gauze N above them was charged positively from a battery. The metal cover MM′ could be removed and replaced at pleasure, and the effect on a delicate quadrant electrometer connected to P observed. By this method considerable tension can be got up on the mineral surface, notwithstanding that it is close upon zero potential. The light effect depends on tension, not potential.

the earth, which is composed of mineral particles charged, as the positive sign of the slope of atmospheric potential indicates, with negative electricity.

It seems to us evident that there exists a direct electric action of sunlight upon the earth, and that we have given experimental evidence in favour of the theory put forward by von Bezold and Arrhenius, according to which the sun acts on the earth, not by electrostatic or electro-dynamic action-at-a-distance, which would involve difficulties of a theoretical character, but through the

medium of the electrical forces of light waves. We hope soon to establish the consequences of this theory in meteorology in another Paper, giving the results of two years' observations on the intensity of the most refrangible rays of sunlight and of the slope of atmospheric potential.

Wied. Ann., 48, p. 338.—Experiments on the Gradient of Atmospheric Potential and on Ultra-Violet Solar Radiation.

Elster and Geitel describe the observations they have made for two years on solar radiation, at observing stations of low and high altitude, as tested by its electrical discharging power; and they plot curves of such effective radiation for days and months along with the curves of atmospheric potential observed at the same places. These curves are of much interest, and need study. Incidentally they find that, of the whole effective solar radiation, 60 per cent. was absorbed at altitudes above 3,100 metres; 23 per cent. of the remainder was absorbed in the layer between this and a station at 1,600 metres; and 47 per cent. was absorbed between this and 80 metres above sea level. Or, in other words, of 236 parts which enter the atmosphere 94 reach the highest observing station (Sonnblickgipfel), 72 the middle one (Kolm-Saigurn), and 38 the lowest (Wolfenbüttel). They discuss the question as to how far the daily variation of terrestrial magnetism is due to electrical currents in the atmosphere excited by sunshine and other meterological matters.

[The Paper and plates are worthy of reproduction in full in the *Philosophical Magazine.*]

Wied. Ann., 46, p. 281. On the Behaviour of Alkali Metal Cathodes in Geissler Tubes; On Photo-electric Discharge in a Magnetic Field; and On the Measure of Photo-electric Currents in Potassium Cells by means of a Galvanometer.

Results:—The resistance of a Geissler tube provided with a cathode surface of pure alkali metal is diminished by the light from the sparks of an induction coil; especially when the pressure is ·1 to ·01 mm. of mercury. The resistance which rarefied gas opposes to an electric current in a magnetic field is greatest in the direction

normal to the magnetic lines. The changes of resistance effected by any kind of light in a vacuum tube with alkali metal cathode can be measured galvanometrically. (A Daniell cell gives 100 divisions on a Rosenthal galvanometer when coupled up through such an illuminated tube, each division meaning about 10^{-10} ampere).

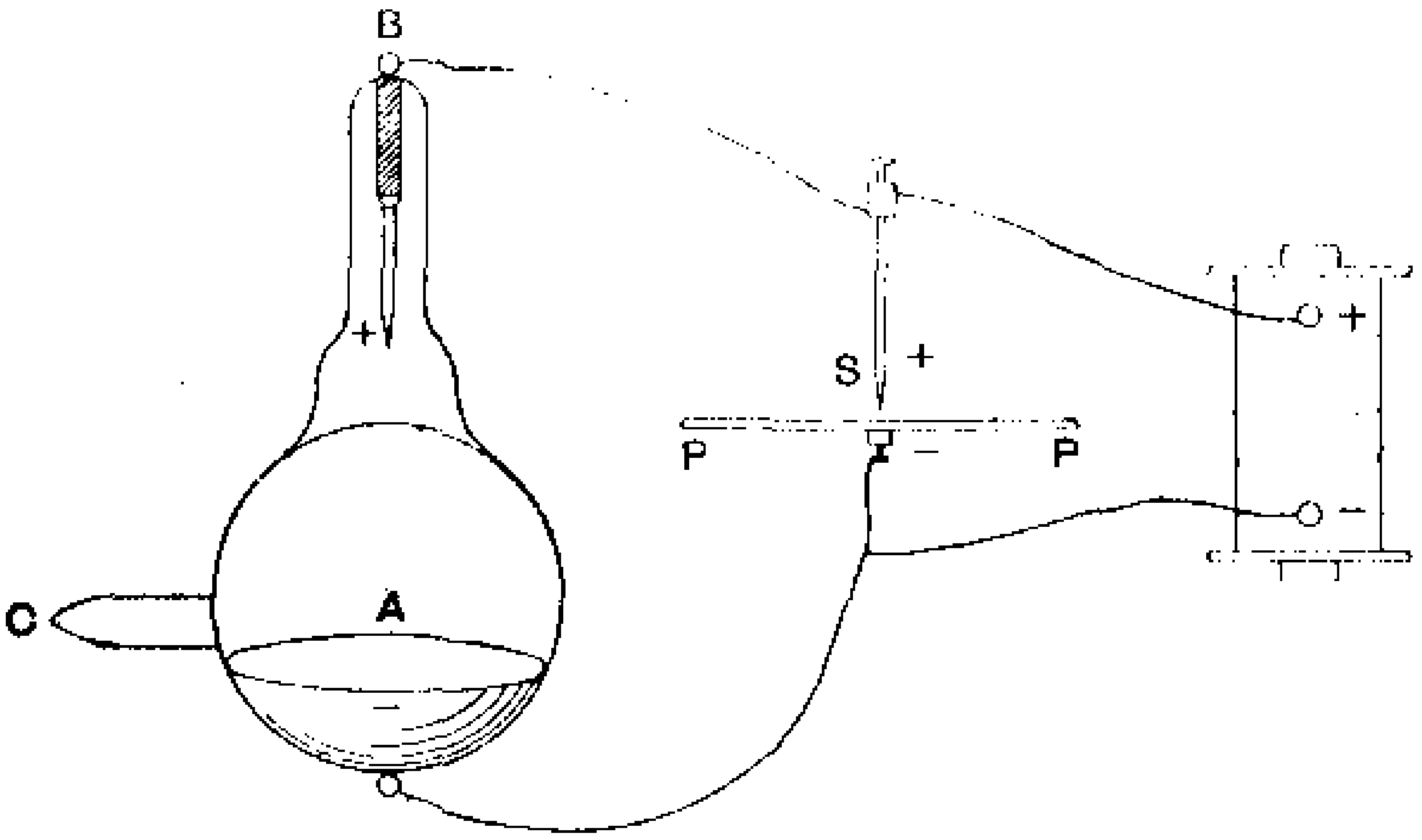

FIG. F.

Explanation of Fig. F.—A vacuum tube of rarefied hydrogen containing alkali metal as cathode, say the liquid K – Na alloy, or solid K or Na. A spark gap at S serves as alternative path, and a stream of sparks can occur to the plate P in the dark. But when light falls on the surface A, this stream of sparks can cease, showing that the resistance of the vacuum tube is diminished.

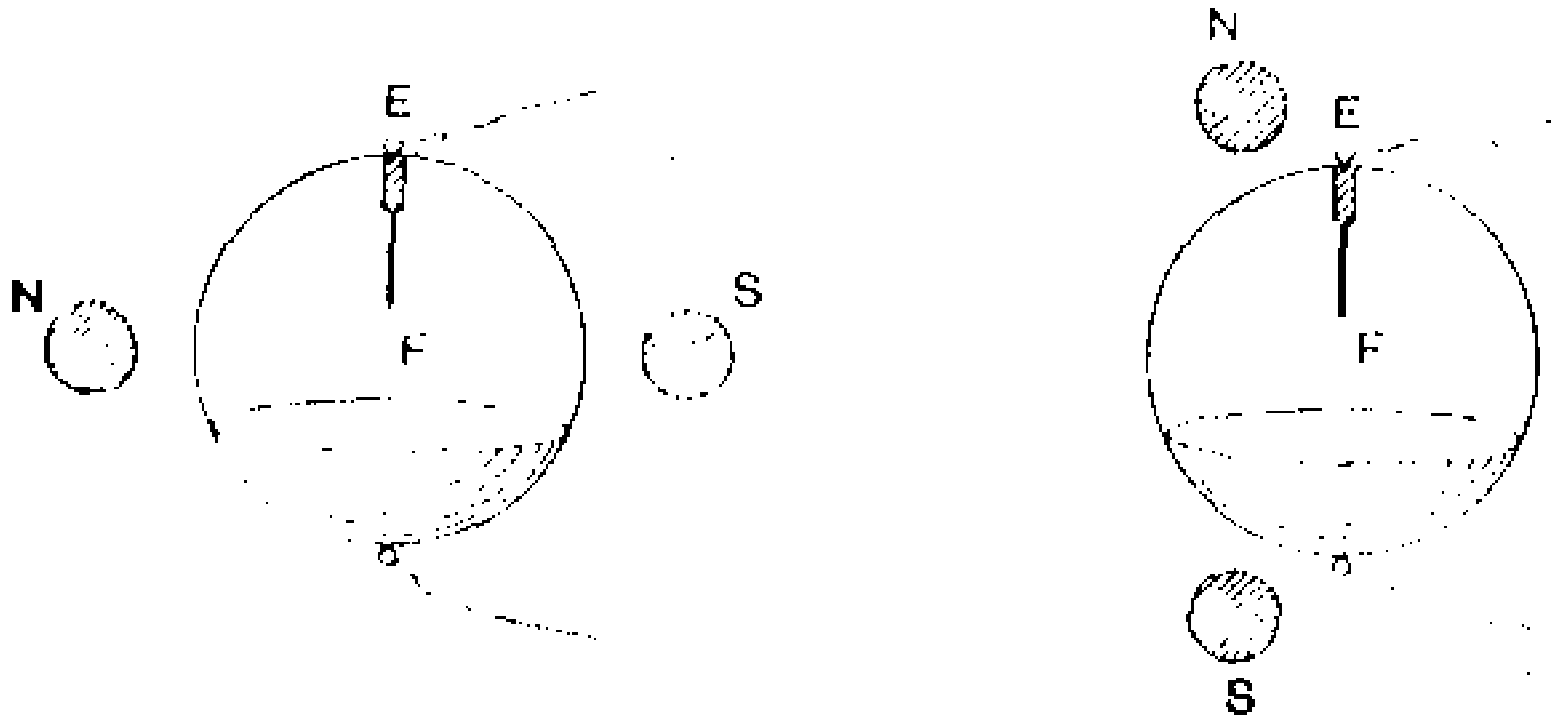

FIG. G.

Explanation of Fig. G.—Showing position of magnetic poles with respect to the vacuum tube discharge. With the poles *across* the line of discharge, as in Fig. on left, excitation of the magnet opposes the leak from the surface. With the poles as in Fig. on right, the discharge is not much affected—it is even sometimes slightly increased.

Wied. Ann., 48, p. 625. On the Photo-electric Comparison of Sources of Light.

Attempts to make such a potassium cell into a photometer.

Wied. Ann., 52, p. 433. Further Photo-electric Experiments.

Plates of platinum, silver, copper need exceedingly ultra-violet light before they show any photo-electric power ; zinc, aluminium, magnesium show it for visible violet and blue light ; the alkali metals, in an atmosphere of rarefied hydrogen, advance their range of sensibility into the spectral red ; while under the most favourable conditions they show a sensibility only inferior to that of the eye itself. The Authors now use galvanometric methods of measuring the effect, instead of only electrometers, and they arrive at the following results :—

(1) The three alkali metals Na, K, Rb, have different sensibility for differently-coloured lights. For long waves their order of sensibility is Rb, Na, K ; though Rhubidium is far exceeded by the other two metals in white light.

(2) Illumination of a plane alkali-metal cathode surface with polarised light causes greatest discharge if the plane of polarisation is normal to plane of incidence ; and least, if the two coincide.

[This is a most remarkable observation. Its probable meaning is that the electric oscillations of light are photo-electrically effective in so far as they are normal to the surface on which they act ; while electric oscillations tangential to the surface are scarcely operative. Different angles of incidence must be tried before the proof is complete.*—O. J. L.]

(3) Electric oscillations of very short period, such as are given by a Hertz oscillator, are commutated by illumination in the presence of alkali metals in rarefied gas, so as to be able to set up a constant electric tension in the gas.

[A Zehnder tube* was used, and the momentary phases of the oscillation during which the metal is negatively charged are apparently taken advantage of by the illumination.]

* The result is to show that an incidence of about 60° is the most effective, but the effect at perpendicular incidence is far from being zero. The matter seems to be connected with the polarising angles of metals.

(4) The photo-electric dissipation shown by powdered fluor-spar is dependent on the colour of the mineral, in such a way that the deepest blue violet or green specimens are the most sensitive.

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* See Fig. 13, p. 16.

APPENDIX II.

PHOTO-ELECTRIC RESEARCHES OF M. AUGUSTE RIGHI.*

M. Righi has observed the following facts : (1) That ultra-violet rays reduce to sensibly the same potential two metals placed near each other (plate and gauze parallel and close) ; (2) That several photo-electric couples of this kind can form a battery ; (3) That a simple metallic plate charges itself positively under the influence of radiation ; (4) That a voltaic arc formed with a zinc rod gives the strongest effect, while the sun gives none.

Besides these facts he finds :—(*a*) That certain gases and vapours, such as coal-gas and CS_2, absorb the active rays strongly.

(*b*) That if the discharging body is easily movable it recedes like an electric windmill.

(*c*) A film of gypsum interposed between gauze and plate charges itself negatively on the side facing the negatively-charged plate.

(*d*) Radiation produces its discharging effect even on non-conductors (ebonite and sulphur). With glass, resin and varnishes the action is feeble, or nearly nothing.

(*e*) If the experiment is made with a copper gauze and a zinc plate, the phenomenon nearly disappears on varnishing the gauze. His hypothesis is that radiation produces convection of negative electricity, the carriers being molecules of air.

(*f*) The carrying molecules move along the lines of force, and throw electric shadows. To show this he varnishes a zinc cylinder, all except a generating line, charges it negatively to 1,000 volts with a dry pile, and places it parallel to a large earth-connected plane, which has a narrow rectangular portion insulated from the rest and communicating with an electrometer. Light only acts on the uncovered line of the cylinder, and on turning the cylinder round the electrometer is only deflected when it is exposed to

* *Comptes Rendus*, vol. 107, p. 559.

some of the (circular) lines of force emanating from the active line of the cylinder.

(*g*) *Radiation charges positively an insulated metal, even when* it is an enclosure with walls of the same metal; the metal being certainly uncharged at the beginning of the experiment. The same occurs with sulphur and ebonite. If there is a feeble initial *plus* charge, radiation increases it.

(*h*) While the discharging power of radiation for negative electricity is strongest with zinc and aluminium, and slower with copper and gold, following the Volta series; the E.M.F. set up by radiation, when it charges things positively, is greatest with gold and carbon, and less with zinc and aluminium; *again following the* Volta series, but inversely.

(*i*) If radiation falls on an insulated metal plate connected with an electrometer, in an enclosure of the same metal, the positive electrification shown by the deflection of the electrometer is greater *as the plate is further from the walls of the enclosure. The action* stops when the metal has attained a certain electric density, constant for a given metal; so the potential of a plate is naturally higher as its capacity is less. It is thus established that radiation acts on the particles of gas in contact with a conductor; *they go away with a negative charge, leaving plus on the conductor*, until an electric density sufficient to balance this action is attained.

(*j*) It is probable that if the solar rays do not produce an effect it is because of the absorbing action of the atmosphere. In fact, if one places a tube whose ends are glazed with selenite between the source of light and the metals being experimented on, the effects become sensibly stronger when the tube is exhausted.

APPENDIX III.

ELLIPTICALLY POLARISED ELECTRIC RADIATION.

Since the delivery of my lecture to the Royal Institution, on June 1st, Herr Zehnder has published* a mode of getting elliptically and circularly polarised electric radiation. He takes a couple of plane-polarising grids, such as are depicted in Fig. 21, page 33, and places them parallel to each other at a little distance apart with their wires crossed.

If the two grids are close together they will act like wire-gauze, reflecting any kind of polarised radiation equally; but if the warp and woof are an eighth-wave length apart, and the plane of the incident radiation is at 45° to the wires, the reflected radiation will be circularly polarised. A change in the circumstances will, of course, make it elliptical. Such a pair of grids acts, in fact, like a Babinet s Compensator.

* *Berichte der Naturforschenden Gesellschaft zu Freiburg i. B.*, Bd. IX., Heft 2, June 21, 1894.

APPENDIX IV.

ON MAGNETISATION PRODUCED BY HERTZIAN CURRENTS; A MAGNETIC DIELECTRIC:*

BY M. BIRKELAND.

"Two years ago† it was proved by conclusive experiments that Hertzian waves travelling along an iron wire magnetise transversely the very thin layer into which the alternating current penetrates, and whose thickness does not exceed some thousandths of a millimetre. Once proved that alternate magnetisation can be produced with such rapidity, other questions present themselves. One asks, for instance, if it is not possible to demonstrate in magnetic cylinders stationary magnetic waves analogous to the electric stationary waves along metallic wires."

The author finds that the conductivity of massive iron makes it an unsuitable substance, and uses instead a mixture of iron filings, or of chemically-obtained iron powder, with paraffin, to which he sometimes adds powdered quartz. This he moulds into cylinders, and inserts as the core of a spiral in an otherwise ordinary Hertz resonator.

The figure shows emitter and receiver drawn to scale; the magnetic cores are introduced into the spiral A, and their effect on the length of the resonator spark is observed. With this arrangement of exciter the *electric* effect of the spiral is negligeable, since it is well removed from electrostatic disturbance, and subject only to magnetic. The spiral is of 12 well-insulated turns, the spark-gap is a micrometer with point and knob, and a pair of adjustable plates to vary the capacity for purposes of tuning.

* Abstracted from *Comptes Rendus*, June 11, 1894, and communicated by Dr. Oliver Lodge.

† Why two years ago? It was practically proved by Savart early in the century, and has been observed over and over again since. However, it is true that experiments have been more numerous and conclusive of late, and have been pushed to very high frequencies.—O. J. L.

He employed 12 different types of cylinder, all about 20 centimetres long, and 4 centimetres diameter.

1. A massive cylinder of soft iron.

2. A bundle of fine iron wires embedded in paraffin.

3—9. Six cylinders of the agglomerate of chemically-reduced iron in powder and paraffin, containing respectively 5, 10, 15, 20, 25, and 50 per cent. of iron.

Then for control experiments :—

10. A cylinder of agglomerate of zinc powder in paraffin, with 40 per cent. of zinc.

11. A cylinder of brass filings in paraffin, 20 per cent. of metal.

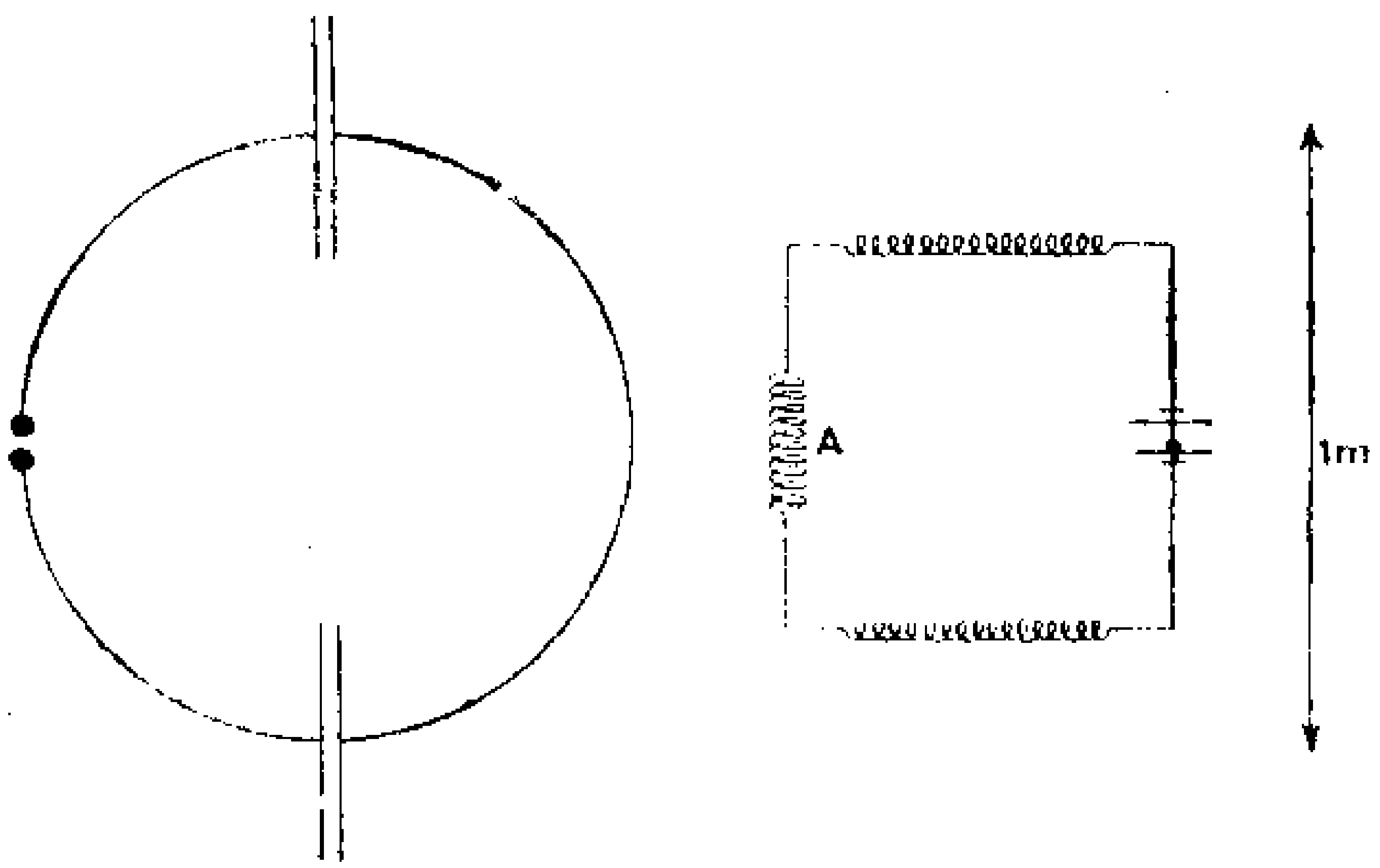

FIG. 1.

12. A tube of glass, 4·5 centimetres diameter, filled with various electrolytes.

The manner of observing was as follows (the experiments were done in the laboratory of Hertz) :—

The resonator, with its spiral empty, was syntonised with the exciter, and the maximum spark measured. It was between 4 and 9 millimetres long in these experiments. Then one or other of the above cylinders was introduced and the spark-length measured afresh.

Cylinder 1 did not affect the maximum spark-length. Cylinders 2—4 reduced the maximum spark to $\frac{1}{10}$th of its former value ; 7 and 8 to $\frac{1}{100}$th, and No. 9 to $\frac{1}{200}$th of its former value (viz., from 9

millimetres to ·05 millimetre). Nos. 10 and 11 had but a feeble action, they reduced the spark from 8 to 7 millimetres.

Tube No. 12, filled with distilled water, scarcely affected the spark length ; the period of the secondary increases a little, but the maximumspark is the same as before, once syntony is re-established. Filled, however, with dilute sulphuric acid containing 10, 20, or 30 per cent., the tube reduced the spark considerably, in each case about the same, viz., from 9 to 1·3 about. (Currents induced by Maxwellian radiation in electrolytes had been already observed by J. J. Thomson).

While trying to re-establish syntony between primary and secondary, I found that the period of the resonator was considerably increased by the cylinders 2–4, but that the maximum spark length was much diminished. With the cylinders Nos. 5—9 in the spiral, it was no longer possible to establish syntony, "a fact which is certainly due to their considerable absorption of energy. Take, for example, cylinder 9 : electro-magnetic energy must converge rapidly towards it in order to be transformed, and the space finds itself empty of energy as air is exhausted of vapour in presence of an absorbing substance.

This absorption is probably due to hysteresis in the ferruginous cylinders ; the development of Joulian heat, so typically shown by cylinder 12, being undoubtedly of the same order in cylinders 3—9 as in Nos. 10, 11.

It is probably by reason of this absorption that I have not succeeded in establishing stationary magnetic waves in a circuit of ferro-paraffin."

If one of the cylinders, 2—9, is wrapped in tinned paper before introducing it into the spiral A, its action is completely stopped. (These conducting cores *diminish* the period of the resonator ; it is much as if the spiral A were partially shunted out ; but the maximum spark returns as soon as syntony is re-established.) To examine this further he enclosed the cylinder in drums of cardboard having fine wires either along generating lines, or along circular parallels. The latter suspended the action of an interior ferruginous cylinder, the former did not.

To find to what depths the magnetism penetrated, Birkeland inserted hollow ferruginous drums into A, measured their effect,

and then plunged solid cylinders into them to see whether the effec-increased.

He thus found that the magnetisation easily traversed 7 millimetres thickness of the 10 per cent. ferro-parraffin, and 5 millimetres of the 25 per cent.

The substance is comparable to a dielectric on the theory of Poisson-Mossotti.

"The results obtained with our magnetic dielectric invite to new researches"—such as the mechanical force excited by electric waves on a delicately-suspended ferro-paraffin needle, and the rate of propagation of Maxwellian waves through such a substance.

APPENDIX V.

THE HISTORY OF THE COHERER PRINCIPLE.

The following, written by Dr. Oliver Lodge, appeared in "THE ELECTRICIAN" *for November 12th, 1897, and is given here with the view of keeping the reader in touch with the progress (from the earliest recorded Hertzian wave work to the present time) in the development of the Coherer:—*

Probably the earliest discovery of cohesion under electric influence was contained in that of old forgotten observation of Guitard in 1850, that when dusty air was electrified from a point the dust particles tended to cohere into strings or flakes. The same thing no doubt occurs in the formation of snowflakes under the influence of atmospheric electrification; and the cohesion of small drops into large ones in the proximity of a charged cloud is exceedingly familiar, since it results in the ordinary thunder-shower. Great light was thrown on these meteorological phenomena by the discovery of Lord Rayleigh in 1879 of the curious behaviour of a small fountain or vertical water-jet when exposed to the neighbourhood of a stick of excited sealing-wax. A smooth orifice being arranged to throw a jet of water about three or four feet nearly vertically, the jet breaks into drops, and the drops scatter in all directions, rebounding from one another and giving a shower of fine spray; but if a stick of sealing-wax be rubbed on the sleeve of a coat and brought within one or two yards of the place where the jet breaks into drops, it will be found that the scattering ceases, the fine spray is no longer formed, and the broken jet rises and descends in great blobs of water. The rain-shower has, in fact, been converted into a thunder-shower. Further experiments, conducted chiefly with two jets, elucidated the phenomenon.* Arranging two nearly parallel jets from neighbouring orifices so as to impinge against each other, they were found ordinarily to rebound after colliding, a sort of film or superficial layer appearing to prevent amalgamation of the jets into one; but if a slight difference of electric potential were maintained between the two jets, say by connecting them to the terminals of a

* *Proc.* Roy. Soc., 1879 and 1882.

Leclanché cell, then the boundary layer broke down,—the two colliding jets no longer separated with a rebound, but amalgamated and became one.

Lord Rayleigh developed a similar explanation for the single jet. The scattering of the jet in its ordinary state was due to the rebound of colliding drops, as could be *seen* by examining it with a sufficiently instantaneous or intermittent mode of illumination; but if an electric charge were in the neighbourhood it must be supposed that a trace of potential difference existed between the drops, which caused them to amalgamate into one whenever they collided, and thus speedily to become united into a comparatively few large drops, which then continued on their parabolic way.

At first sight it would seem as if the neighbourhood of a negative charge should charge all the drops positively at the place whence they break off from the earth connected parent jet, and should thus cause them all to repel each other. And if the electrified sealing-wax is held too close, this is exactly what happens. All the drops are then similarly electrified, and scatter more violently than ever, never in that case coming into any rebounding or other contact with each other. But under a gentler electric influence the similar charging has a less marked result, and a polarisation difference of potential of one or two volts may without difficulty be supposed to exist in the air between drops, partly because they are not all equally charged and partly because each is a conductor acted on inductively by a neighbouring electrified body. In this connection it must be remembered that rubbed sealing wax is at a potential of several thousand volts, and therefore can readily cause a potential gradient of two or three volts per millimetre throughout a yard or two of space.

The next stage was the rediscovery, in 1883, of Guitard's old dust phenomenon by the present writer and the late J. W. Clark (*Nature*, July, 1883; *Phil. Mag.*, March, 1884), when they were working together at the dust-free region seen over hot bodies when strongly illuminated in dusty air. The fact of such dust-free spaces was discovered by Tyndall, and they can readily be seen by placing a lighted spirit lamp or a hot poker in the beam of an electric lamp. Tyndall thought the dust was calcined or burnt up, and that thus the air was freed from it; but this is an utterly erroneous explanation, and the true explanation is of a more recondite character, being connected with the bombarding effect of gas molecules as illustrated in Crookes's radiometer. The dust particles are beaten away from

the hot body by a molecular bombardment, which manifests itself even at ordinary pressures on bodies of sufficiently small size, as indeed was also otherwise shown by Tait and Dewar and Osborne Reynolds in the course of remarkable theoretical and practical investigations.*

Before arriving at this explanation, however, we experimented to see if the phenomenon was caused by the air having become slightly electrified, perhaps by reason of its having streamed as an upward convection current over the surface of the warm solid, at which we were looking, in a thick smoky atmosphere, in the concentrated light of an electric arc. We therefore purposely electrified the rod, to see what that would do, and we found to our surprise, directly the electric machine was turned, that the smoky atmosphere almost instantaneously disappeared, and the box became quite clear.

This experiment, after development, though described in July, 1883, was shown in public for the first time at the Dublin Royal Society (*Nature*, April 24, 1884), and subsequently at the British Association meeting in Montreal† in 1884, and was applied to the experimental clearing of rooms from dense smoke or fume. It has often been shown since, by Mr. Swan and others, and has become fairly well known.‡

The next observation of cohesion under electrical influence was made by the writer in 1889, while working at the protection of telegraphic instruments and cables from lightning,—a research which resulted in the use of choke coils as supplementary to the air-gaps of the ordinary lightning guard, and thus to the forms of instrument constructed by Dr. Alex. Muirhead for telegraphic work in this country, and to the supplementary additions adopted by the Westinghouse Company for their non-arcing guards adapted to electric light and power installations in America. The observation of cohesion was a bye-issue, noticed when the knobs of the lightning guard were brought too close together.§

* "Dimensional Properties of Matter," *Phil. Trans.*, 1879.

† Evening Lecture on "Dust," by the writer, see *Nature*, Vol. 31, p. 265; also *Journal* of the Royal Institution, May, 1886.

‡ Apparatus for the purpose is now in the catalogue of Messrs. Ducretet, of Paris, but they supply a pair of combs of points. It makes a more interesting experiment if only one point is used, in a moderate space, and the electric supply regulated so as not to hurry the disappearance of the smoke too quickly, but to exhibit the stages of aggregation which precede the final disappearance by deposition. Any kind of smoke serves, but a bit of magnesium ribbon burnt under a bell jar is cleanly and effective. It should be looked at in a window or other good light, of course.

§ *Journal* of the Institution of Electrical Engineers for 1890, pp. 352-4.

When lightning itself strikes a guard, it has indeed often been found that the opposite sides of the protective air-gap are fused together. This, no doubt, may be partly due to a straightforward melting or welding by heat, but it is probably not solely that. Molten metals without a flux do not so readily weld. It is almost certainly due to a cohesive action also, the difference of potential between the molten terminals resulting in adhesion and amalgamation, a phenomenon also observed in the frequent locking of an electric arc formed between two metallic electrodes. However this may be, certainly the phenomenon occurs on a small scale, for if the pair of knobs or points placed as a shunt to protect a galvanometer or other telegraphic instrument from lightning (or what is easier experimentally and essentially the same thing, from a Leyden jar discharge) be set too close together, the galvanometer will be found to be short-circuited after a spark, and the knobs will be found, both by mechanical and electrical tests, to be feebly united at a single point.* Not only, however, is the galvanometer short-circuited by the metallic junction so formed, but at the instant of the formation of the joint it experiences a very perceptible kick, indicating a momentary current, coincident no doubt with the electric discharge but one from which it would have been protected had not the junction occurred. The galvanometer kick is clearly an effect due to the uniting metals, but it has not yet been fully elucidated; it may possibly be thermo-electric, as Prof. Hughes, who first observed it, thinks likely; but it may also be electro-chemical, or it may be connected with an effect observed later by FitzGerald in his galvanometer mode of detecting Hertz waves, which he published at the Royal Institution in 1890. The point of present interest is the cohesion which sets in between the knobs when the spark occurs: an extremely feeble spark was found sufficient to produce the effect, provided the surfaces were already almost infinitely close together, *i.e.*, provided they were already in what would be called contact, with the merest imperceptible film of (probably) oxide separating them, just the kind of film which a chemical flux is useful in removing. The electrical stimulus appears to act as such a flux, and the adhesion of the two surfaces was demonstrated by an electric bell and single cell in circuit. Every time the spark occurred the bell rang, and continued ringing until the table, or some part of the support of the knobs, was tapped so as to shake or jar them asunder again.†

* "Modern Views," second edition, p. 359.

† *Journal* of the Institution of Electrical Engineers, 1890, p. 352.

If the electric bell stands on the same table as the support of the sparking knobs, or, still better, if it be put into mechanical contact with them, its tremor is quite sufficient to break the contact asunder again; unless the spark, and therefore the adhesion, has been too strong. Raising the bell into the air, it ceases to interrupt the spark-induced continuity, and in that case continues to ring; but directly it is replaced *so that its vibration can reach the cohered surfaces through* their solid supports, and not only through the air, it usually happens that a few strokes—often, indeed, the first stroke—of the bell, sometimes even the incipient movement of the hammer preparatory to a stroke, is sufficient to break the circuit and suspend instantly the action, restoring the gap to its original condition and leaving the circuit ready to be completed again by another spark.

The spark in these experiments was usually supplied from the outer coats of a pair of oppositely-charged small Leyden jars, whose knobs sparked into each other; the idea being to ascertain all the conditions pertaining to the feeble residue of a lighting discharge which is liable to be conducted by telegraph wires to a distance, and there cause some damage to sensitive instruments not suitably protected from sudden electric jerks, whose laws of flow are quite different from those proper to steady currents.

Meanwhile, in 1887 and 1888, had been performed the great experiments of Hertz on electric waves in free space. The writer, assisted by Prof. Chattock, had also made some experiments concerning the production and detection of waves on a system of long parallel wires stretched on insulators across and around a large room, and excited by the discharge of a pair of condensers, an arrangement very similar to that now known under the name of Lecher; and clear experimental evidence of the existence of nodes and loops on such wires, as well as a method of approximately measuring the wave-length, was given.* The brush luminosity of the wires, afterwards observed more strikingly by Tesla, were also seen and shown to the Physical Society. The interest of these experiments was, however, altogether eclipsed by the brilliant and masterly investigation at Carlsruhe by Hertz, who, as everyone except the British public is aware, put into practice FitzGerald's 1883 suggestion that Leyden jar discharges should emit Maxwellian radiation, and conclusively demonstrated the existence

* Verbally to Section A at Bath, 1888. *See* also *Phil. Mag.*, August, 1888, p. 229; and *The Electrician*, Vol. 21, pp. 607-8.

and some of the properties of such waves by this very means; using, however, Leydens of small capacity, and with the coatings well separated, so that the electrostatic energy of the charge should have an intensity comparable with the magnetic energy of the discharge, even at some distance from the circuit.

The whole subject of electric waves was thus laid open to physicists, and many have been the workers in the field. Trouton, of Dublin, worked long and successfully at their optical analogies, with the very inadequate means of detection then known;* and since better means have been known perhaps the most complete set of experiments published, after Hertz himself, is that contained in the book "Optice Elettrica," by Prof. Righi, of Bologna; but some account of several previous researches is contained in the second edition of "Modern Views of Electricity," in the chapter called "Recent Progress," of date 1892. The means used by Hertz and his immediate followers to detect the waves was simply the little spark which they excited in conductors upon which they fell, electric currents being set up in such conductors by the act of reflection. The effect was often at that time attributed to electric resonance or syntony, but there was very little true resonance in these experiments; the first swing was usually much more powerful than any of the succeeding ones, and was competent to cause the little spark; if it failed the remainder of the swings had but a poor chance of success. Consequently precision of tuning was not really important, though no doubt it would help a little.

It is interesting to note that a magnetic needle detector not unlike Rutherford's had been used long ago by Joseph Henry at Washington, and that minute induced sparks, identical in all respects with those discovered by Hertz, had been seen in recent times both by Edison and by Silvanus Thompson, being styled "etheric force" by the former, but their theoretic significance had not been perceived, and they were somewhat sceptically regarded. Yet Henry, even in those pre-Maxwellian days, was led to an intuition concerning the spread of electrical disturbance surprisingly near the truth. The truth indeed it was in some sort, but it was not worked out or grasped in detail, and so cannot be considered as more than a brilliant guess; but the fact that an observation of the widespread surgings induced in the neighbourhood of a primary discharge had been made by Henry, and had been seen by others to be

* *Nature*, Vols. 39 and 40.

capable of giving actual sparks, before the time of Hertz, although it has no real bearing on Hertz's fresh discovery, and did not lead those who like the writer had long been trying to think of a detector for Maxwellian waves to discover one, nevertheless is instructive as showing how frequently it happens that a fact is lying ready to hand but is not taken up and appreciated until some special or extra stimulus has been supplied.

After Hertz's results had become well-known, the writer devised a plan whereby real electric resonance could be demonstrated with a pair of actual glass Leyden jars of ordinary pattern, by connecting each to a discharge circuit, the one complete, the other with an air-gap, and providing the first or receiving jar with an overflow path or bye-circuit provided with an air-gap across which a visible spark could occur whenever the induced oscillations or surgings accumulated in its main circuit were sufficiently intense to make the jar overflow.* The air-gap was most easily provided by a strip of tinfoil pasted over the lip of the jar, but it served equally well if wires led from the two coatings to a pair of adjustable knobs near together, like a lightning guard, between which the overflow spark could pass. The same knobs indeed were used as had already served for the lightning experiments; and, as in that case, if the knobs are arranged very close together and are put in circuit with a battery and a bell, cohesion sets in and the bell rings whenever the overflow occurs. The bell continues to ring until the stand is tapped, but if the bell itself touches the stand or the table, it rapidly breaks contact by its vibration, exactly as described five paragraphs above. Closed Leyden jar circuits are not strong radiators, nor was this resonance then observed excited by true waves. No attempt was at this time made to apply the cohesion principle to the detection of true Hertz waves such as could be felt at a considerable distance from a strongly radiating source.

Before this time, FitzGerald and Trouton had hit upon their galvanometer method of demonstrating to an audience the occurrence of the minute scarcely-visible spark in the gap of a Hertz receiver.†

Prof. Minchin also, working at Cooper's-hill with his sensitive photo-electric cells, especially with some which he called

* *Nature*, Vol. 41, p. 363; or, "Modern Views of Electricity," second edition, p. 338.

† *Nature*, Vol. 41, p. 295; and Vol. 42, p. 172.

impulsion cells that behaved abnormally when subjected to taps or other mechanical vibrations, found that when Mr. Gregory was working a Hertz radiator in another part of the same laboratory the electrometer connected to his cells responded.* Many other detectors have been devised and used, but this one of Minchin's almost certainly depends on the cohesion principle, though its action seemed paradoxical then. Moreover he was able, by its aid, to signal without wires over a considerable number of yards, at that early date 1890 and 1891.

About the same time, Prof. Boltzmann used a charged gold-leaf electroscope for the same purpose, having it so arranged that the electroscope was on the point of discharging across a minute air-gap, so that its leaves were dilated by a definite amount. The slightest excess of charge would make it discharge and the leaves instantly collapse. In this charged condition it was sensitive to very minute electric surgings, and if Hertz waves were excited in another part of the room, the wave disturbances caused the gap to break down and the electroscope leaves to collapse.† This method is not a cohesion method, but it led the writer, when subsequently repeating Boltzmann's results with modifications, to realise that, if the gap were almost closed, cohesion could be made to set in by the surgings induced by regular Hertz waves.

The Boltzmann gap method was accordingly modified in several ways; one way was to make it of carbon and to connect it, with its wave collector, to the terminals of 110 volt electric light leads, so that whenever a Hertz vibrator was discharged and induced a minute spark across the gap, that same spark might close the circuit and establish an arc. This plan forced itself on my attention by the behaviour of sundry Swan lamps suspended with shades so as to illumine my lecture table, which became short-circuited whenever a large Hertz vibrator was at work; for the lamps were at that time kept from rotation, and thereby from glaring into the eyes of the audience instead of being screened from them, by a couple of copper wires stretched across the theatre; so long as those wires were there, the fuses used to blow whenever a Hertz oscillator was started; an experiment which was interesting enough, and was shown to several people, including, I think, Prof. FitzGerald, but which was sufficiently a nuisance to necessitate the wires, which were acting as collecting wires, being taken down and replaced by stretched silk threads, which are there to this day.

* *Phil. Mag.*, March, 1891; also January, 1894.

† *Wied. Ann.*, Vol. 40.

Another modification was to connect the gap to an Abel's fuse or to a gas leak, which exploded or ignited under the influence of a feeble spark. Yet another was to connect it to a single cell and electric bell or galvanometer, as already explained.

Meanwhile, however, and well before these later experiments on the detection of Hertz waves were in progress, certain discoveries had been made by M. Branly, Professor of Physics in the Catholic Institute of Paris, which were of the greatest interest and importance. Prof. Branly had found that a coat or varnish of fine copper dust, porphyrised copper or other such substance, though it could only conduct a current very feebly, and much as a blacklead pencil trace conducts, under ordinary conditions, yet fell in resistance enormously whenever an electric spark occurred in its neighbourhood; somewhat in the fashion that the resistance of selenium falls on exposure to light. It is not clear that M. Branly recognised that he was dealing with Hertz waves or true electrical radiation, but his observations were most satisfactory and conclusive, and he measured the reduction of resistance caused in a number of different substances, including an assemblage of metallic filings, and conglomerates or paste of filings in various viscous liquids and in dry powders. Moreover, he found that the spark was still operative in reducing resistance even when it was several yards distant.

The account of Prof. Branly's experiments is to be found in a couple of short communications to the French Academy of Science (*Comptes Rendus*, Vols. 111 and 112) and the writer had intended to reproduce in abstract the gist of these memoirs; but to readers of *The Electrician* this is unnecessary, as a descriptive article from *La Lumière Electrique* has already been translated in full in July and August 1891 (see *The Electrician*, Vol. 27, pp. 221 and 448). Unfortunately the writer, in common perhaps with others, must confess to having overlooked these articles at the time, probably by reason of their coincidence with the holiday season. In his second edition of "Modern Views of Electricity," published in 1892, though he refers on page 359 to the cohesion principle in this connection, the writer is clearly ignorant of Branly's experiments.

The matter seems to have been ignored in this country till 1892, when Dr. Dawson Turner described the experiments to the British Association in Edinburgh, and even till 1893, when Mr. Croft brought them to the notice of the

London Physical Society. Prof. Minchin at once realised that here was a phenomenon analogous to what he had been observing with his impulsion cells, and after a few trials wrote a Paper to the Physical Society recounting his repetitions and modifications of Branly's experiments.* This Paper, before it was read, was circulated by the Society to its country members, and so came tc the eye of the writer, who at once wrote a short note summarising some of his work in the same direction, and pointing out that this discovery of Branly's, thus made known to him, was another case of the electrical cohesion phenomenon already observed by several experimenters. This is published along with Prof. Minchin's Paper in the *Phil. Mag.* for January, 1894, and to it the friendly reader is referred. The writer at once proceeded to try the Branly tube of filings, and found it far superior in manageability to either the Boltzmann gap or his own delicately adjusted cohering knobs; though immediately afterwards, he and FitzGerald together arranged a single point coherer, of iron and aluminium (point of sewing needle resting on aluminium foil), of what was at that time extraordinary sensitiveness and of reasonable manageability. A whole series of quasi-optical experiments were then undertaken with the new detector, and were shown to students and to the the Liverpool Physical Society; moreover, before long, various improved methods of arranging the filings were gradually adopted, especially by sealing them up in vacuum or in an atmosphere of hydrogen (" Work of Hertz " book, page 30) so as to protect them from continued oxidation by the air, and to prevent the film which hypothetically separates the surfaces from growing too thick. Indeed, brass filings in hydrogen speedily got *too* clean, and became so sensitive that it was almost impossible to restore the original high resistance by tapping. Consequently, a perfect or Sprengel vacuum was preferred to hydrogen, Almost any filings tube could detect signals from a distance of 60 yards, with a mere six-inch sphere as emitter and without the slightest trouble, but the single-point coherer was usually much more sensitive than any filings tube. Mr. Shelford Bidwell has also worked with varieties of powder.

The tapping back was at first performed by hand, and for optical experiments this is still, perhaps, the most convenient plan; but automatic tappers were very soon arranged, just as with the old knobs; an electric bell mounted on the base of a filings tube (*see* page 27) was not found very

* *Phil. Mag.*, January, 1894.

satisfactory, however, because of the disturbances caused by the little sparks at its contact breaker, to which the previous coarser knob-arrangements had failed to respond; so a clockwork tapper, consisting of a rotating spoke wheel driven by the clockwork of a Morse instrument, and giving to the filings tube or to a coherer a series of jerks occurring at regular intervals, to imitate what the writer supposed must occur in the eye, viz., a restoration to sensitiveness after an interval corresponding to the persistence of impression, was also employed. Many of these things were shown at a Friday evening lecture at the Royal Institution on June 1, 1894, while others were shown at the British Association meeting at Oxford. In both cases signalling was easily carried on from a distance through walls and other obstacles, an emitter being outside and a galvanometer detector inside the room. Distance without obstacle was no difficulty in these experiments, only free distance is not very easy to get in a town, and stupidly enough no attempt was made to apply any but the feeblest power so as to test how far the disturbance could really be detected. Mr. Rutherford, however, with a magnetic detector of his own invention, constructed on a totally different principle, and probably much less sensitive than a coherer, did make the attempt and succeeded in signalling across half a mile, full of intervening streets and houses at Cambridge.*

Numbers of people have worked at the detection of Hertz waves with filing tube receivers, and every one of them must have known that the transmission of telegraphic messages in this way over moderate distances was but a matter of demand and supply; Sir W. Crookes, indeed, had already clearly stated this telegraphic application of Hertz waves in the *Fortnightly Magazine* for February, 1892, and refers to certain experiments already conducted in that direction,† the details of which are unknown to the writer. There remained no doubt a number of points of detail, and considerable improvements in construction, if the method was ever to become practically useful; but these details could safely be left to those who had charge of the Government monopoly of telegraphs, especially as their eminent Head was known to be interested in this kind of subject.

Meanwhile the optical developments of the matter excited most interest among physicists, both here and on the continent; the writer performed some experiments of the kind, Righi per-

* *Phil. Trans.*, 1897, A., communicated to the Roy. Soc., June, 1896.

† Quoted in *The Electrician* "Notes," October 1, 1897.

formed many more, and Prof. Chunder Bose, of Calcutta, repeated several of them with additions and improvements, using as detector a sort of half-way house between a point coherer and a filings tube by squeezing a few little rolls or spirals of wire between a point and a micrometer screw. Restoration to sensitiveness was in this case achieved by relaxing the pressure of the screw; and the writer has not found Bose's form of coherer specially convenient; but Prof. Bose's whole apparatus, constructed as it was precisely on lines published by the writer in his lecture and little book on "The Work of Hertz, &c." was well designed in detail and exceedingly compact, being on the scale of an ordinary goniometer; and with it many experiments familiar in ordinary optics could readily be shown with electric radiation.

In all the optical experiments made by any of these observers it was customary to place the axis of the emitter either horizontally, or vertically, or inclined, in other words to emit radiation polarised in any azimuth (or rather altitude), and to arrange the collecting part of the receiver to correspond or otherwise, according as response or no response was desired. In fact, observations on polarisation were the easiest and the most instructive that could be made with the definite kind of radiation now for the first time at command. The rotation of the plane of polarisation, the conversion of plane into elliptical polarisation, the amount of radiation reflected by substances at different angles and different aspects with regard to the direction of vibration, were readily observed. Furthermore, ever since Hertz's first discovery, whenever waves had to travel through a metal grid or alongside a plane conductor, it was natural to arrange the electric oscillations so as to be normal to the conducting lines or plane, for if they were tangential they excited electric currents therein, and their energy became wasted in the production of heat. So, in so far as earth and water are conductors, it is desirable to use radiation polarised in a horizontal plane, *i.e.*, with the electric oscillations vertical, if considerable distances are to be traversed by it.

With respect to an explanation *why* metallic cohesion is caused under electrical influence, the following considerations are offered :—

Mr. Rollo Appleyard made a liquid coherer of two globules or pools of mercury, side by side and touching, but kept apart by a thin film of grease, such as is easily given by a coat of paraffin oil. Connecting up a battery cell to these mercury

pools through a key, he found that every time the key is depressed the pools move together and become one; he points out moreover that mercury globules shoot out a tentacle towards the positive terminal (on the principle of the capillary electrometer, of course), and this must be taken into account in any coherer theory.* Lord Rayleigh, knowing already that electrical cohesion existed between liquids, also devised a liquid form of coherer, and exhibited it at the Royal Institution. It is interesting to observe that in a mercury form of coherer an appreciable time interval occurs between the depression of the key and the amalgamation of the mercury, the lag looking as if a film had to be mechanically squeezed out between the oppositely-charged mercury surfaces, and as if this took a perceptible fraction of a second to accomplish. This experiment conveys the useful suggestion that cohesion may in all cases be the result of electrostatic attraction, and that the molecular films separating solids in contact may thus also have to be squeezed out, though as they only touch at single points such extrusion is almost instantaneously achieved. This may very likely be the chief cause, for although a true electro-chemical extension of the range of cohesion between polarised molecules had seemed to the writer to be a possible explanation also, he now perceives that the electrostatic force alone may be sufficient. For it is easy to calculate the force of attraction between two surfaces differing in potential by a volt, and separated from one another by the smallest known thickness of thin film (which is 10^{-7} certain, or 1 millimicron, called $\mu\mu$ by microscopists); such force per unit area would be given by the square of the potential gradient divided by 8π, that is, it would amount to $\frac{1}{25}\left(\frac{10^7}{300}\right)^2$ dynes per square centimetre, which equals 44 atmospheres, and is a very considerable pressure. Ten times this attractive pressure would exist if the surfaces were within really *molecular* distance of each other, in addition to the force of true cohesion which would then, still more powerfully, operate; but the film thickness assumed above is such as would just prevent the force of cohesion from effectively acting across the gap, and would leave the electrical attraction due to the one volt alone. Three and a-half volts could therefore squeeze metals together with a force equal to a ton load per square inch, and might thus be sufficient to cause them to weld or unite, especially if the electric stimulus simultaneously

* *Phil. Mag.*, May and July, 1897.

acted in any way as a flux, by reducing the infinitesimal tarnish of oxide or other compound which must be supposed normally to cover them. The noble metals are not well suited to coherer purposes; they are too clean. In so far as the approximate contact is not between *surfaces*, but between points consisting of relatively few molecules, the attractive pressure is greater rather than less. Thus to take an extreme case, the attraction between two oppositely-charged molecules differing only by a volt from each other, and separated by a thin film like the black spot of a soap-film whose thickness was so admirably measured by Profs. Reinold and Rücker, is over 1,000 atmospheres in intensity.

These differences of potential across the films cannot continue for any time, unless a battery is used, for the films do not really insulate; they are able however to act as dielectrics for an instant, and to be burst with what we must be allowed to call a spark, if the momentary strain caused by the impulsive rush of electricity is too great.

Such, so far as the writer is aware, was in general terms the state of theoretical and practical knowledge, at least in this country, on the subject of coherers in relation to Hertz waves; when, in the autumn of last year, there came a new development. A student in Italy, having learnt from Prof. Righi about the production and transmission of Hertz waves across space, and their detection by the cohesion which they caused in a group of metallic filings, and, being gifted, doubtless, with a sense of humour as well as with considerable energy and some spare time, proceeded to put a form of coherer into a sealed box and to bring it to England as a secret device adapted to electric signalling at a distance without wires. Being influentially introduced to the chief engineer of the Government Telegraphs, who, presumably, was too busy to remember what had recently been done in the Hertz-wave direction, the box was announced as containing "a new plan" which had been "brought to England." Lectures were given on it at both the Royal Institution and the Royal Society, the House of Commons voted £600 for special experiments, and trials were made by the experienced official staff with their usual skill. Mr. Marconi is to be congratulated on the result of his enterprise; the newspaper press of this and other countries have taken the matter up, popular magazine articles have been written about it, and so now at length the British Public has heard, apparently for the first time, that there are such things as electric waves, which can travel across space and

through apparent obstacles to a considerable distance, and can there be detected *in a startling fashion*. Thus the public has been educated by a secret box more than it could have been by many volumes of Philosophical *Transactions* and Physical Society *Proceedings*; our old friends the Hertz waves and coherers have entered upon their stage of notoriety, and have become affairs of national and almost international importance. Every daily paper now has bulletins concerning the progress of the practical application of the invention, except in so far as it is still being privately worked at by uninfluential individuals.

Leaving the scientific aspect of the question, the writer feels that the work of Mr. Marconi has been distinctly useful, and that due credit belongs to him for having stirred up the British Nation and interested the European Governments in these experiments. It is evident that in the present state of the law and of general education no ordinary methods of publication are adequate to arouse sufficient interest for the inauguration of practical applications. It can hardly be considered that this state of things is satisfactory, but so long as it continues the intervention of an intermediary between scientific workers and the public is essential, and his services are universally recognised.

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